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14. ABSTRACT
This chapter presents a conceptual design process based on the experience with the Multimodal Watchstation (MMWS) project. A significant part of this process lies in the definition of tasks and establishment of key requirements. An HCD focus characterizes tasks in an information system work space according to task qualities and dynamic properties. This task-centered approach drives design thinking toward solving users' needs across a broader spectrum of task types and dynamics than is typically considered by systems designers.

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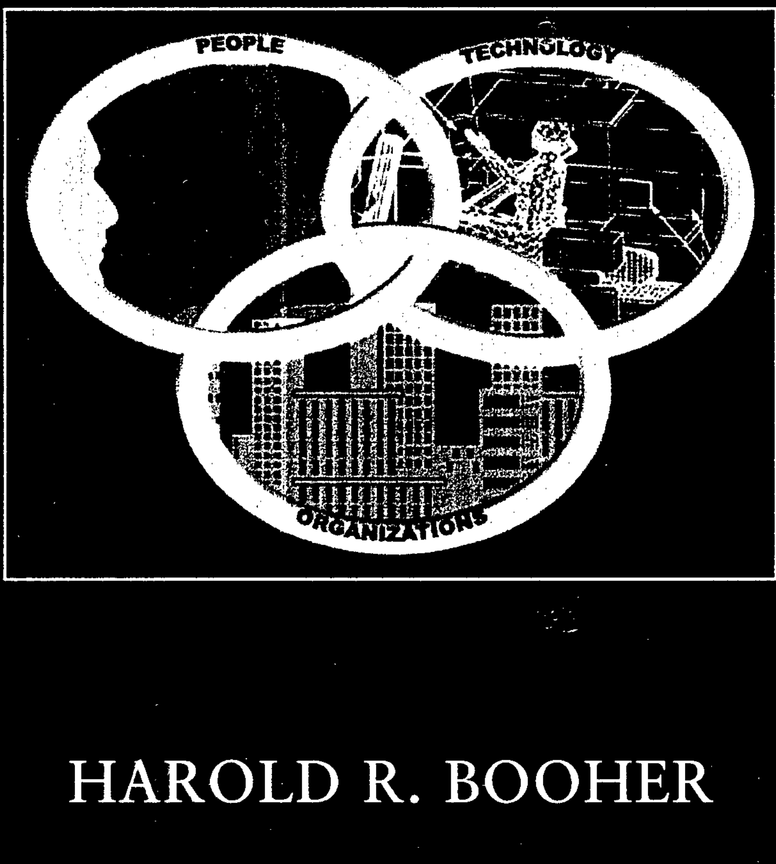

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CONTENTS

CHAPTER 20

Human-Centered Shipboard Systems and Operations

GLENN A. OSGA

20.1 BACKGROUND

One of the primary principles of successful human systems integration (HSI) in systems engineering and management is utilizing a human-centered design (HCD) approach throughout the systems acquisition process (Chapters 1, 10, and 18). Several other chapters (Chapters 4, 6, 7, and 9, in particular) have pointed out the need to establish HSI requirements early in the process, if the HCD principle is to be fully effective. Unfortunately, system design requirements based upon human capabilities and limitations may not be considered early in the design process, leading to costly changes during implementation. Often, new systems simply evolve from past systems approaches using established procedural and design methods.

The designer may rely on the user during the requirements stage to consider the human component, but user input must be carefully considered in that it can maintain previous designer flaws relative to human performance. User input and design qualities must be abstracted into basic task requirements. Unless the methods and procedures used in establishing requirements are specifically analyzed for impact on human performance and efficiency, neither the user or the designer is likely to fully recognize the effect the design will have on the human component when the system is fielded.

A major requirement for improved user interface and decision support aboard ships has arisen from the need for crew size optimization. Optimization must be achieved without sacrifice of performance, mission risk, and without crew overload. Crew optimization in future ships has been recognized as a significant cost factor and therefore has become a performance capability objective for newer classes of ships [Naval Sea Systems Command (NAVSEA), 1996, 1997]. When the U.S. Navy required a drastic reduction of crew size from 350 to 95 personnel on DD 21 ships, it recognized the need to use HSI principles for equipment design requirements and design solutions to successfully achieve mission objectives (Bush et. al., 1999).

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Consequently the Multimodal Watchstation (MMWS) project was conceived as a risk-reduction research effort to create concept designs that aid in HSI with optimized crews.[1] The concept designs also demonstrated a *task-centered approach* to requirements determination during the system definition stage, without major restrictions imposed by current design practice.

20.1.1 Multimodal Watchstation Project

As an example of the early stages of the design process and its products, MMWS represents the conceptual design stages of engineering, before full-scale development is attempted. The purpose of concept definition is not to create a product for final delivery or fielding but to investigate innovative features that are hypothesized to improve human performance and training. This process further refines requirements and guidelines that are then transferred into advanced engineering model development. The reader must recognize, however, that the primary MMWS project focus is on software-based decision aids and not on watchstation hardware or display technology. The hardware design is totally driven by available commercial display and control technologies, with some innovation in how the technologies are integrated and used by the software, together with ergonomic features for the physical configuration. As display technologies improved over the project life, the watchstation was also modified to take advantage of these changes. The primary focus of the MMWS design project was simulation-based design, in which a user interface simulation was constructed to test and refine requirements.

The conceptual design process included the identification of critical tasks within one of the two broad mission domains and the specification of task requirements based on task characteristics and job design. This evolutionary approach allowed for technology insertion and improvements over the 4-year MMWS concept design cycle, with operator involvement in all stages of the design process.

Over the 4-years to complete the project, requirements were generated using a task-centered design approach from which alternative design concepts were developed. The design concepts were subjected to a series of usability tests and team performance evaluations to verify that both human performance and training objectives could be met. Performance and workload measures were collected with reduced crews relative to today's systems estimating the potential impact on crew size optimization.

The iterative design process resulted in a mission execution and management system prototype capable of simulating work activity typical of navy command and control information centers and designed for meeting mission goals for both land attack and air defense operations. The warfighting functions supported by the MMWS are the same as current command and control centers but offer reduced workload and workload distribution capabilities among team members that may enable crew size optimization.

The work discussed in this chapter applies directly to the ship command center information systems design and does not imply that crew size is reduced for other ship operational functions as a result. Decision support systems, cooperative automation, and effective displays are enablers of optimized crews but do not directly reduce crew size, unless other operational methods are changed.

The path from requirements to effective display and interface design is multidimensional. If requirements omit major work factors that contribute workload or performance risk, the resulting design solution is at risk. There is a degree of art and innovation in

design not easily quantified, and it is likely that multiple design solutions can work to achieve acceptable performance as well. Despite this first impression that one design example and set of requirements only serve as a loose connection with other designs, we are seeing a broader use of decision support "components" that are modified across diverse mission areas, without the need to "reinvent the wheel" for new task requirements. The specific design properties that address the task-centered requirements identified in the MMWS project also apply to other mission areas and work settings such as ship propulsion and engineering tasks (Osga, 2001).

Thus, an important lesson learned to retain throughout the chapter discussion is that the *type of requirements* and *type of tasks* covered are stable within the task-centered approach across diverse systems. This stability allows for modification of various design components to "fine-tune" results for various missions, such as defensive, strike warfare, and ship engineering control. In all cases, the human has a need to project mission events ahead in time in order to visualize the upcoming processes and anticipate potential results. It is then possible to enact mission solutions based on lower stress planned responses rather than on surprised and late reactions to failures.

The advantage of HSI research and development in the early conceptual process is that design ideas of varying risk can be combined and tested, with the ability to accept or reject design solutions based on iterative modeling or human performance testing. This design process will vary between every project based on the cost and expertise of the design team. Important qualities of the MMWS decision aids were defined through years of focused research related to the air defense task domain. The project allowed the integration of various design concepts and techniques in a common design approach. Important innovations were newly derived, however, based on task support areas not previously addressed.

20.1.2 Chapter Overview

This chapter presents a *conceptual design process* based on the experience with the MMWS project. A significant part of this process lies in the definition of tasks and establishment of key requirements. An HCD focus characterizes tasks in an information system work space according to task qualities and dynamic properties. This *task-centered approach* drives design thinking toward solving users' needs across a broader spectrum of task types and dynamics than is typically considered by systems designers.

The chapter is divided into the following sections that describe how HSI requirements were defined and design solutions for these requirements were addressed in the MMWS project:

- Task-centered approach
- Task coverage requirements
- Human support task requirements
- Dynamic task requirements
- Design by task requirement
- Other design qualities
- Benefits of task-centered design

20.2 TASK-CENTERED APPROACH

The task-centered approach fits into a conceptual design process, as shown in Figure 20.1. The process is iterative and cyclic, meaning that not all system design components and features are fully developed at the same time and fully output to another design processing stage.

First, mission and task requirements are derived from design reference missions (DRMs), which capture the future use of the system into a time-based story depicting system use. The quality of the DRMs is critical for system requirements and definition of scope.

Mission tasks are then derived as part of an iterative function allocation process, with levels of desired automation considered for each task. The function allocation may not be entirely fixed in a dynamic system in which the user can vary function allocation. This phase of processing produces the DRM, task definitions, task flows, and decision points to describe the task domain.

The human–computer interface (HCI) design is developed and validated, as shown in the lower right circle in Figure 20.1, with input from related discovery research and other decision support tools that may be modified to fit the current mission focus. Important design requirements (beyond just the mission task requirements) that feed this part of the design process are discussed later in the chapter.

The software validation process and prototyping are conducted to verify that computational methods can be found that are reliable, accurate, and serve the information needs of the tasks. This prototyping process can be separate from the HCI prototyping and requirements definition thus enabling HCI designers and software engineers to coordinate work in a parallel process. The HCI prototypes, whether in paper, slide show, or simulation may be subject to repeated usability tests before they are submitted to the software prototyping process. As usability data is collected and HCI requirements mature and are better specified over time, they serve as input to the software validation process.

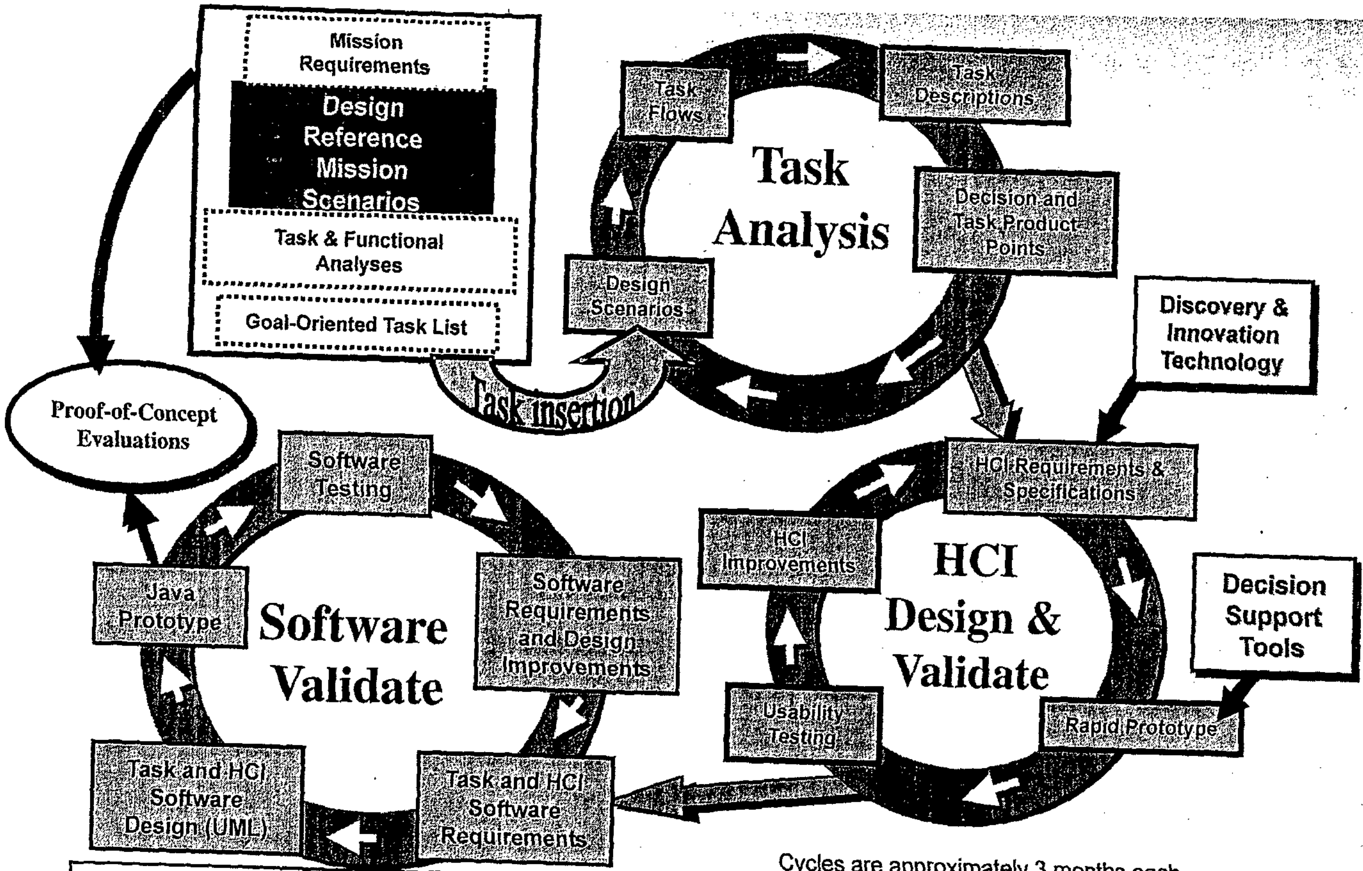
An important facet of this approach is that in large complex systems, requirements and design are not fully described as in a hierarchical noniterative approach but that testing and refinement can occur over time for "pieces" of the system. The software architecture is also designed to accommodate successive improvements over time. The chapter content primarily covers the "task analysis" and "HCI design and validate" parts of this design process.

Before proceeding further into the design process example with MMWS, several important terms used throughout the chapter should be defined. Several basic definitions related to "tasks" are needed to better understand the *task-centered approach* as a design process. These are *task, mission task, task description, job design*, and *task definition*.

A *task* is a goal-oriented work activity component of a job. The task may be accomplished manually, automatically, or some combination of the two. The composite of all tasks for a given job description accounts for all workload during a prescribed work period.

Mission tasks are workload producing components typically addressed in military system specifications involving human control elements.

A task description represents a taxonomic description of labeled work activities. This creates a written description of a definable process by which human and machine cooperate at achieving a work-related goal.



Products Summary
Task Cycle: Task Descriptions
HCI Cycle: HCI Component Descriptions, look-and-feel demonstration
Software Cycle: Software requirements, software design (in UML notation), working software demonstration.

Figure 20.1 Conceptual design process incorporating a task-centered approach.

A *job design* is a collection of tasks defined as a set of related work goals to which a human operator is assigned to complete.

Task definition is the process of putting defined labels on a set of work activities. There is no unified, agreed approach within the human-engineering discipline on task labels. Typically it is up to the system designer and architect to define a hierarchy and level of detail judged appropriate for the design problem.

The *task-centered approach* is an analytical HSI design process broadly comprising two components:

- Defining HSI requirements within defined task domains
- Creating task-centered designs supporting task goal achievement

Defining HSI requirements is the focus of the remainder of this section and Sections 20.3, 20.4, and 20.5. Creating task-centered designs is the focus of Sections 20.6 and 20.7.

20.2.1 Establishing Key HSI Requirements

The premise is that a task-centered design focus during the systems engineering process provides a mechanism to fully describe the work environment in a manner that establishes a comprehensive set of design requirements. These requirements are structured to cover the various types of tasks that compose the majority of workload sources at the tactical watchstation. Another important premise is that design attention must be paid to the major sources of workload whether they be mission, computer-interface, human information processing, or work management tasks. These tasks also operate in a dynamic work cycle with defined phases. Much of today's design focus in legacy ship systems is on a narrow subset of processes within the task work cycle, leaving the system operators unsupported to use their visual and cognitive resources to carry the workload through the unsupported task phases.

A process that is key to successful HSI is adequate description of the system task and work environment. A design concept is simply a set of design hypotheses matching design solutions to the task requirements, with the hypotheses being made relative to the human performance outcome in both training and operational results. A task-centered approach can be used to directly tie requirements to task characteristics.

The most important concepts utilized in establishing key HSI requirements are:

1. *Task Coverage* The quantity of tasks and the qualities of task requirements addressed by the designer relative to the entire workload environment within the job design. A major concern here is the breadth of the tasks in job design. If a task is not even considered or recognized by the designer, then there can be no hypothesized design solution. Most of the major types of tasks (e.g., mission, computer, work management, and human support tasks, along with the various types of support requirements for situation awareness, attention management, and decision making) can be developed through the method of task definition. These types of requirements can be thought of as "static" task requirements, in the sense that task qualities can be described independent of time or sequence.

2. *Task Dynamics* The life cycle of a task within a dynamic task decision process. The dynamic properties of tasks are described with reference to how these dynamic

properties create additional design requirements. For example, human memory is subject to decay over time. Task interruptions are affected by time. Task deadlines and parallel tasks affect workload. The dynamic pacing and workload requirements of the job environment are not readily visible when each task is analyzed independently and out of the timing context.

3. *Task Goals* The detailed level focus of system design needed to create the task product in an efficient and cost-effective manner.

Task coverage and task dynamics will be covered in more detail in the following sections, but since the process of establishing key HSI requirements starts with task goals, they are described in the following section.

20.2.2 Definition of Task Goals

The goal of many mission tasks is to create a product (e.g., an order, control action, message, awareness update), but a task-centered design goal is often a process. For example, to reduce human cognitive workload, the task goal may be to move tasks from requiring knowledge-based aptitudes toward the skill or rule-based performance (Rasmussen, 1986). For such tasks the goal would be to relieve the user of tedious rule- or skill-based steps, by capturing such processes within algorithms or computational resources that result in the presentation of "draft" task products for human verification and delivery. Thus, as designers we shift the human role in system interaction from repetitious lower level task rules toward a role of monitoring and directing automated processes that produce "draft" products for human inspection.

The purpose of a task in the context of human work is for the useful completion of work related to mission goals. The definition of task goals is critical in early design stages in that they describe any gaps between the conceptualized system products and the task goals that the human must support. As we see in the *task definition process* described in the next section, the scope of these goals may be broad or narrow depending on the vision of the designer and the acknowledgment of the types of tasks and their associated goals.

Goals can usually be stated in hierarchical terms, and the designer must make important design decisions as to what type of functional system support to provide toward the attainment of task goals at various hierarchical levels. See Example 20.1.

Example 20.1 Message Preparation Requirements The task of message preparation and delivery to meet a mission requirement may be supported across various subtask steps of information collection, message creation, editing, formatting, and delivery. A word processor may support the functional goal of writing text in the message format with various features to support text editing. Consistency across messages may be supported by display views that show proper message format. The system could collect the proper information for the message and prepare a draft message if the form and content is known. The same function can be supported with only a basic word processor, forcing the user to collect information and type in the message based on training and task expertise. With minimum support, the user must collect the information from displays, form the message content in their head, and verbally speak the message to the receiver while perhaps writing notes with no system support for creation, editing, and delivery. In each example, the task goal remains the same for the user—deliver a correct, timely, and succinct message as soon as it is required—but the requirements for system support would vary tremendously depending on how much automation and task product drafting the system is required to support the user. Task-centered design attempts to

identify requirements related to task goals and provide support through all task phases leading to the goal accomplishment.

Many task performance goals could be derived from mission performance requirements. If the requirement is set at five messages per minute or no more than 5 percent error in message content, the contractor and designer must determine a human–system solution that meets performance goals. Without the specification of performance goals, design becomes a somewhat arbitrary process of debate between the human factors engineer and project management on what level of system support is proper or needed. Unfortunately, the definition of performance requirements and design solutions often does not involve the human component. When focused correctly technology support could often provide improved performance with improved HSI, resulting in more accurate adjustment of task performance goals and mission requirements based on those improvements.

The research process should play an important role in the setting of task goals. In an impartial lab setting, task goals are not artificially held back or restricted by business practices, risk aversion, or loyalty to a specific product or approach. Research must identify tasks and goals representative of operational requirements. Results should provide "honest broker" evaluation of a system's qualities and its potential to support task goals. Setting of task goals represents common metrics of quality across disparate design approaches, and as such, the goals create the opportunity to specify performance objectives as metrics of system success.

Task goals provide a focus for design of task products, and task coverage defines the breadth of design support toward the attainment of the variety of task goals. Sections 20.3, 20.4, and 20.5 describe how HSI task coverage and task dynamic requirements were developed for the MMWS in support of various task goals.

20.3 TASK COVERAGE REQUIREMENTS

Task coverage represents the amount of work activity that the designer supports with system features. In the MMWS project, task coverage represented a comprehensive view of the work requirements for an air defense mission application, and a "task to be covered" was defined as a segment of a job activity with the following attributes:

- Varying in time from seconds to hours, or the entire watch period (6 hours or more).
- Supportable by computer-based aids, (e.g., not work activities such as physically connecting cables or cleaning and maintenance).
- Supportable by various levels of automation, which may include user selectable or fixed automation levels. Thus, levels of task supervision and user–system task sharing are dynamic.
- May vary from structured, rigid protocols to open-ended user-defined sequences. Following Rasmussen's (1986) hierarchy, tasks may include skill-, rule-, or knowledge-based behaviors. Many tasks in the air defense warfare area had defined procedures and structured protocols and could be defined as rule-based tasks.

Task coverage is strongly influenced by designer *vision, cost, and time*. Often the *potential* system support is a result of design *vision* to see how *potential* technology,

algorithms, and computational methods can be utilized in support of tasks. During early design concept formulation, user task activities must be discussed and judgments rendered as to whether the activity is "too difficult" or "too costly" to support. Revised design vision might appear weeks or months later during the task definition and analysis process. The level of task support may be increased with upgraded versions of the software and system. These successive improvements create a requirement for a flexible software architecture to allow for expanded user support while task requirements evolve. Thus, during the early stages in the conceptual design process, it is imperative to identify as complete a concept of task coverage as possible, while avoiding premature narrowing of design focus because an immediate solution is not readily available.

A significant step in the *task coverage analysis process* is to identify all the critical task goals in the job domain. *Task definitions* are strongly related to task goals. These goals are a starting point from which to create task definitions. For example, the goal to create and send a new track report message in MMWS is covered under the task with the same name "create new track report." Other goals such as "review rules of engagement" have the goal of updating short-term memory during the mission progression with information that affects other task decisions. Thus, task goals may be to produce defined products such as a mission order, mission report, message, plan, etc., or the goal may be to update and reinforce information storage supporting situation awareness in the human cognitive processor.

Subject experts are able to define concrete task products relatively easily but appear to have much more difficulty with goals that are related to cognitive processing. This process can be aided by task walkthroughs or observations of task progress with experts used to explain these processes. The task definition process must be as thorough as possible to ensure that complete coverage is considered, and the level of functional support within the coverage area is based on deliberate design decisions on how much workload to allocate to human or machine to cooperatively achieve the goals.

For MMWS design purposes five main classes of tasks were defined as requiring support by the watchstation design. These classes were:

1. Mission tasks
2. Human support tasks
3. Work space computer management and control tasks
4. Work management tasks
5. Communication tasks

These classes represent a total task coverage approach to the MMWS workload. Within each of the classes of tasks, the process of task definition was applied to create task labels that made sense to both designer and subject expert, and were explainable and defendable to software engineers and project management.

20.3.1 Task Definition Process

The process of task definition may differ significantly if the system design problem is an upgrade to an existing task process or if the system is a new or innovative concept. With system upgrades there may be increased pressure from current users and management to minimize impact on training or documentation costs. With a new system there is less

legacy and design tradition to affect the task definitions. Designers must analyze the current task process carefully and define task elements at different levels. The designer must look for inefficient or awkward methods in current procedures. These factors affect the manner in which the task taxonomy is described and then formulated for the new system.

Subject matter experts (SMEs) will most likely describe their tasks within the scope of the current work environment. Some air defense warfare tasks were initially omitted in MMWS because the current design provided little or no support for those tasks; therefore they were not part of the software description or documentation. Without some introspection and observation of current task processes in action, these undocumented tasks remain invisible to the designer. Also, the goal of a task can be obscured by lack of full documentation of the current systems' task process. For example, the SME might guide the task definition and process for a communications task toward designing refinements to support that process, hence focusing the design discussion on improving today's process. With tasks related to voice communications, the SME drove the design discussion toward better communication methods or technologies. Further analysis on the *task product* changed the task definition by revealing a potential improvement in performance by focusing on the preparation and delivery of the tasks' communication products.

Example 20.2 Human Factors and Computer Science Collaboration During Task Definition The MMWS design hypothesized that perhaps a voice message can be prepared automatically and sent digitally without requiring the human to both conceive and verbalize the report through a communication channel. The human factors engineer estimated a reduction in workload if this technology can be implemented while the computer scientist determined if there was sufficient task structure to automate the message preparation. When the task requirements are stated first, it allows greater flexibility in the design discussion than if the design solution is discussed first.

A key lesson learned during the MMWS project was to define task "products" first or early in the task definition stage. If a product cannot be clearly defined, the task concept may be a candidate for being "reduced" to a task "step" or "subtask" within another defined task area.

With system design changes, tasks may become obsolete or technology can change the entire nature of the task or process. Tasks may evolve from totally manual to partially automated to produce "intermediate" products in a multistage complex process. Other tasks have easily defined beginning and end points and concise products. There are no clearly defined quantitative solutions to defining the best "size" and workload of the work activity within a given task label. The function of "job design" is to subgroup tasks and work in a manner that allows user work pacing and rest in manageable cycles. Typically, the more concise and smaller the task with respect to time, complexity, and steps, the less likely the task will be interrupted, left incomplete, or subject to forgetting. Fewer tasks relate to a more manageable design problem, software effort, and user training effort. Smaller tasks with simple procedural steps produce easier training challenges that may be presented in a building-block fashion. The ability to combine smaller task products into larger outcomes also facilitates training and instruction. Guidelines for the purpose of defining task size and complexity in MMWS include the definition of a task unit that is:

A "trainable unit" (e.g., a cohesive and related set of goals)

A reasonable software design/build module (e.g., a related set of computations and results)

A reasonable grouping of information and goals (e.g., related information and logical process flow)

The task definition process may generate confusion about how to define the differences between the qualities of "tasks" and "functions." A function is *what* is done and a task is *how* it gets done. For example, a function could be described as "mission planning" whereas the task would be to "prepare the strike mission plan." The task also has associated subtasks such as "receive and review ops orders," "review auto assignment of weapons to targets," or "review and edit schedule." The auto assignment task is supported by the system functions that calculate the best weapon–target pairing. These types of functions were termed "task services" in MMWS. Tasks were defined as processes involving various levels of human intervention, while functions could be either fully automated computations or have human involvement.

During the process of defining MMWS tasks, a taxonomy of work tasks was created and then evolved over time as tasks were defined, created, deleted, combined, or separated. This happened over a period of several months as the work environment and task products became better defined.

This evolution was necessary as the design team completed the initial task description process. This definition and refinement process was supported by teams, comprising SMEs, human factors engineers, and computer scientists. The role of each discipline was valuable as the computer scientist was concerned about how to computationally model the task; the SME carried the perspective of real-world constraints, procedures and operations; and the human factors engineer presented the perspective of design impact on human performance.

The task definition process must also remain flexible through early design stages. Some work activities initially defined as tasks requiring human processing later became more fully automated after further study found analysis methods to create reliable task products without human intervention. These tasks then became task services in support of other tasks. Thus, function allocation was not a one-time event, but instead involved the creation of a set of hypotheses that were refined as task methods were created and matured. The process of defining each of the major task classes is described in the following sections.

20.3.2 Task Properties

The next step in the task coverage analysis process was to conduct a task definition exercise for all of the tasks within the five classes covered. This results in a requirements definition that fully considers unique task properties. A special section follows later for human support tasks. Communication tasks are combined with mission tasks in this discussion. The other three classes, mission, work space computer management and control, and work management tasks are covered in this section.

Mission Tasks are the workload producing components that are typically addressed in naval system specifications involving human control elements. The mission tasks provide a structure for analysis and development of design approaches toward each task goal.

The MMWS analysis for mission tasks was difficult because current naval systems have minimal task design documentation (Osga, 1989). Another difficulty confronting the analyst was the sparse information regarding future shipboard tasks. The analyst, therefore, had to take the following steps:

1. Abstract information from current task methods
2. Project design and technology properties forward in time for new tasks
3. Reanalyze the newly designed task structure

Air defense mission tasks initial listings of mission tasks were reviewed (Osga, 1989) as were function analyses for land attack and air missions [Naval Surface Warfare Center (NSWC), 1997, 1998]. An initial set of tasks was derived when a design reference scenario was developed. The reference scenario served to focus the larger set of possible functions and tasks down to a manageable set under the scope of the project. The types of mission tasks analyzed were:

- Visually identify (VID) all unknown air contacts within a defined area of responsibility (AOR).
- Escort air contacts from threat country with aircraft-carrier-based defensive counter air (DCA).
- Issue warnings to threat country aircraft.
- Conduct positive identification of air contacts unable to VID by correlating indications and warning, electronic emissions, profile, point of origin or initial detection, air tasking order and interrogate friend or foe signal (IFF) received.
- Convey internal communications and external communications with air warfare commander, DCA, and carrier.
- Conduct weapon engagement in self-defense.

Within these types of tasks, mission task labels were defined as a "verb–noun" phrase for consistency. Task verbs such as "prepare . . . , check . . . , deliver . . . , review . . . , order . . . , issue . . . " are descriptive of the type of work activity being performed. The task noun can indicate the product of the task, e.g., a "level 1 query, level II warning, new track report, engagement order, etc."

Work space computer management and control tasks involve the workload that is inherently part of operating within the computing environment. In a graphic user interface (GUI) environment, workload may be induced by tasks such as searching for files, organizing windows, de-cluttering displays, moving and navigating between windows, etc. If the designer is satisfied with accepting an off-the-shelf GUI without consideration to impact on workload or performance, then the system design is accepting a given level of performance. Typical computer control tasks include the selection of displayed objects, resizing of windows, movement of objects, copy and paste text between windows, search for windows, files, objects, etc. The MMWS design included changes to the standard "desktop" approach based on previous research conducted with similar task conditions (Osga, 1995.) The HCI design features were used to reduce workload for computer work space management.

Work management tasks include the management of work activities with regard to work sequence, task prioritizing, multiple tasks time sharing, and scheduling. This work includes the transition between tasks and decisions regarding activity prioritization, e.g., recognizing what is important to do now versus what can be delayed. Individual work management includes decisions regarding multiple task time sharing—when to shift resources from one task to another. Experts, based on training and experience, create a background of work environment knowledge that contains individualized patterns and rules about task start, break, and stop points.

Example 20.3 Expertise in Work Management Tasks An expert knows through repeated task experience that "step 3" in the process is a good time to pause for rest or to shift attention to another task because of on-the-job knowledge gained. The expert anticipates that the next step requires a process that takes several minutes of other system resources (e.g., automation or another user). Thus, the expert gains experience on the systems' *timing* and *dynamics* and can better schedule attention resources during multitasking work events.

Another important aspect of work management is the knowledge of when to begin tasks or sometimes when to terminate them prematurely. Tasks appropriate in one context may be deleted during another. The system design versus cost trade-off for work management tasks is the cost of training and developing user expertise developed over time with reliable repetition versus the cost of developing system support features that aid in reliable work management.

20.4 HUMAN SUPPORT TASK REQUIREMENTS

Human support task requirements are one of the major classes of tasks included in the total task coverage of the MMWS. Special features needing attending in the development of human support task requirements are:

1. Maintaining situation awareness (SA)
2. Attention management
3. Decision making
4. Working memory
5. Task interruption
6. Supervisory control
7. Ergonomics

20.4.1 Maintaining Situation Awareness

Situation Awareness is a human process of information collection, filtering and storage, interpretation, and reaction. System aiding can be provided for various types of SA sampling, storage, and retrieval activities. Jones and Endsley (2000) refer to three levels of SA as:

Level 1: Perception of Elements in Environment Elements are perceived within a volume of time and space. Tasks utilize visual search, filtering of important task

information from peripheral visual "noise," and auditory sampling from multiple circuits. All are part of the sampling process to continually update human awareness.

Level 2: Comprehension of Their Meaning Implies that information presented is compared to the current and near-term goal states of mission tasks and activities to determine the significance of events relative to goals. The result includes decisions to start, delay, or cancel task activities.

Level 3: Projection of Their Status in Near Future This level implies that there is a temporal nature to decision making and that activities may be launched or altered based on projections into the near-term future. In air defense missions, this implies issuing warnings or reports or deciding that such reports are not warranted. There is evidence that users build a story (or mental model) based on the operating environment, expected events, observed events, and compare this to past experiences in their decision-making training or operational experiences (Klein, 1993).

Problems in mission performance may appear when errors occur in SA, producing a mismatch between the user's mental model of the situation and the actual situation. Jones and Endsley (2000) refer to "representational errors" when information has been correctly perceived but the significance of various pieces of information is not properly understood, meaning problems with level 2 SA. In air defense, environment cues that an aircraft is potentially hostile may be overlooked in favor of evidence that it is a commercial airliner, if the event was unexpected that a hostile should be in that location or if there is speed, altitude, or position data suggesting "commercial air." The system requirement, therefore, is to provide information in a manner that *prompts* the user to be attentive and aware of conflicting task data—providing track identification evidence both for and against the current track identification state. The designer must also create methods to support user understanding and projection of events in the near future.

20.4.2 Attention Management Requirements

Attention Management is a critical support activity invoking human cognitive and visual skills. With increasing knowledge and skill of the work environment, the human processor is better able to determine the importance of work events and to disregard background stimulus noise. Human attention resources are limited and are quickly forced to time-share multiple events (visual, auditory) in most tactical situations. The human processor, while conducting task A, must preattend and be ready for task B. Experts develop "work habits" as methods for moving attention resources between task activities. The degree to which the system effectively supports these processes reduces human–system performance variance across the spectrum of users who possess varying degrees of visual search and attention management skills. A significant requirement is to guide attention at an appropriate level of intrusion into the user's work focus using both visual and auditory stimuli.

20.4.3 Decision-Making Requirements

Decision making in naval warfare varies according to the nature of the warfare environment (e.g., rules of engagement, operational orders, battlegroup firing status, and type of warfare: anti–air defense, air offense and strike, land attack strike). In recent years, much attention has been paid to the single-ship, single-threat scenario following the USS

Vincennes incident in 1988. During the 1990s, the Tactical Decision Making Under Stress (TADMUS) program studied air defense tasks with respect to the identification process and displayed information to support decision making with ambiguous ID information (Morrison et al., 1997). The *Vincennes* incident review showed that data within the combat system (such as decreasing altitude of an aircraft) does not translate directly to information for system users if the displays and information presentation do not clearly present *historical trend data*.

When operating in an international battle group under defined doctrine and rules of engagement, the decision-maker's actions must conform to operational rules. As the situation changes from peacetime to hostilities, the decision rules change but the response methods with each task should remain stable. A watchstation design human interface must support all types of tactical situations, ranging from a "single possible threat in peacetime" situation to the "multiple threat hot war situation."

Important requirements must be addressed with respect to information gathering and management for decision support. With an increased system functional role in information gathering and synthesis, the nature of task activity for the user changes from the current "information gathering mode" to the "monitor of intelligent automation" mode. Table 20.1 presents a summary of the changing nature of decision support requirements following a trend away from "manual" information gathering systems toward increased automation for information management. MMWS represents significant progress toward addressing the requirements listed in Table 20.1 but does not completely satisfy them.

Increased dependence on automation support for task information processing will in turn change the information requirements to support the task process. Warfighter needs for "explanation" facilities and supporting information will evolve as systems become more capable of reliable support for multiple tasks throughout the detect-to-engage process. Freeman et al. (1997) identify a "dual-process" model in which decision makers employ either critical thinking or rapid recognition process depending upon the time, stakes, and familiarity of the task and decision context. This requirement for support of both types of decision processes indicates that MMWS information displays must support each decision strategy. See Example 20.4.

Example 20.4 Change in Automation Trust and Decision Processes over Time A reliable identification method that reports a track identification based upon comparing the track information to battle group identification parameters may initially be monitored or even questioned by users (using critical thinking) who will visually check each ID parameter to see if it conforms with the battlegroup rules. If the method is highly reliable (e.g., the system repeatedly creates IDs that match the battle group ID rules), the occurrence of such user checks will diminish (e.g., they will shift toward using rapid recognition processing).

Thus, the decision-making requirements for MMWS were stated as: (1) provide task summary products for rapid recognition processing and (2) provide task amplifying information to aid in critical thinking processes when time is plentiful, stakes are high, and familiarity with the task is low.

The requirements listed in Table 20.1 change the user's role from the current paradigm of checking details of incoming tactical data streams using vigilance and cognitive storage/recall skills (critical thinking detailed), to the role of strategic decision making for more global mission goals (critical thinking globally). The user checks and confirms or denies mission actions recommended by automation support (rapid processing). With

TABLE 20.1 Comparison of Decision Support Methods, Today and in Future

Mission Function	Decision-Making Today	Today's Decision Support Methods	Future Decision Support Requirements
Response planning	• Battle orders and op orders form basis for plans. • User burden on integration of planned responses with system responses. • Selection of ownship plan based on battle group protocols, ownship role, anticipated events, and recent experience. • User burden for plan recall and match with tactical situation.	• Requires heavy working memory loading–storage and retrieval. • No integration of plans with events. • Little or no auto support for planning, testing of plans. • Support for simulated testing of response plans during training.	• Plan templates available for air defense, land attack response tasks. • Ability to compare planned responses to tactical events to trigger tasks. • Quality check of plans—safety, weaponeering, communications, coordination. • Present visual summary of plans.
Detection	• User vigilance of tactical events plays key role. "Hooking and looking" to spot key events as quickly as possible. • Workload often delegated to small part of team.	• Systems record new track positions and kinematics or electromagnetic returns and visually display symbols. • Auditory or visual alert (blinking) provided to enhance detected info.	• Matching of detected events to planned task responses to events. • Summarize info. of detected event and task consequences.
Identification	• User recall of ID factors and manual comparison to system proposed ID. • Single ID check without recheck during track life, requires user monitoring and updating.	• Initial track data is compared to basis ID factors. • ID doctrine difficult to impart to system or explain.	• Clearly summarize all ID factors and comparison to current status whether for/against or unknown in support of ID. • Check ID basis regularly and trigger appropriate tasks if changes warrant.

Monitoring	• User vigilance of tactical events plays key role. "Hooking and looking" to spot key events as quickly as possible. • Time lag or delay of multiple decision support items forces note taking or memory loading. • Workload distributed across team in unpredictable fashion. • Workload pacing forced by tactical actions (external pacing). • Priority of visual search/monitoring based on user expectations.	• The track plot or electromagnetic data log presents current tactical events. • Limited history or projection of tactical events/actions.	• System monitoring of tactical events and triggering of attention direction cues. • Maintain history of events associated with a chain of related tasks (by track, target, or mission function). • Guide attention to most critical events and thus most critical decision actions. • Guide workload distribution to avoid "tunnel vision" and narrow focus based on erroneous expectations.
Response actions Queries Warnings Illumination Jamming DCA intercept Weapon engage Chaff and counter	• Compare tactical events with plans stored in various formats (paper, notes, viewgraphs) or stored in user memory. • Recall similar events on specific track/event in recent history. • Recall and execute steps to complete response procedures.	• Provides manual response methods. • Users must construct many task products manually, e.g., verbal reports constructed by combining pieces of data. • System does not log task occurrences. • Procedures not consistent across similar tasks—training burden increased.	• Provide automatic task responses proposed by system with supervision and approval of task responses. • Provide full explanation of task responses proposed by system. • Provide consistent, redundant, and easily performed methods and procedures.

reliable system performance, the user digs into the background information only if workload allows, or the user questions the result, or the decision has serious mission/safety consequences. Freeman and Cohen (1998) discuss the decision tasks and critical decision points for anti–air warfare in the context of several currently fielded systems. MacMillan et al. (1997) define critical decision points for air defense warfare in a review of current air defense methods for initial MMWS design. The watchstation mission task information was designed to address many of these critical decision points.

20.4.4 Working Memory Requirements

Tasks that evolve over time involve human cognitive processes in short-term or working memory. Information that is processed by visual and attention systems is temporarily stored while the task goal is active. Problems in storage and retrieval may appear when stored information content is similar (Fowler, 1980).

Example 20.5 Information Lost in Working Memory A previously mentioned course change with track 7150 is confused and reported as a change in track 7157 or a few moments later a course heading of 310 is recalled as 030. A common theme in "number reversal" during voice communications may be lack of common visual cues at each end of the conversation to augment the visual information. In today's command centers, information such as electronic warfare emissions may only be available to a single user at a specific workstation designed to receive that information, and results may be only transferred by voice to decision makers. Without immediate note taking upon delivery, such information is easily degraded in or lost in working memory, perhaps within 10 to 20 seconds after arrival (Wickens, 1987).

System design features must be used to unburden working memory, including storage and retrieval of visual information to augment transient auditory information. Also, a combination of numeric and spatial information presentation for track objects supports both verbal and spatial working memory storage.

Example 20.6 Compensation for Short-Term Working Memory Overload by Note Taking An example of short-term task overload in working memory may be manifested in either the repetition or forgetting of task events. Without computer assistance, system users try to compensate for memory limitations through note taking. Observations of operators in action indicate that some write down notes and others do not (Hildebrand, 2000), but there is no known data on the effects of note taking on task outcomes.

System design features that can alleviate memory loading include features that keep track of information changes over time and clearly present past, present, and planned task events. The MMWS Response Planning/Manager is an example of a design feature that provides a visual time review of tasks planned, proposed, in-progress, and accomplished. In today's systems this can only be accomplished by note taking or recall from short-term memory.

20.4.5 Task Interruption Requirements

Mission demands for real-time multitasking require increased designer focus on supportive workstation tools that take into account human limitations resulting from multitasking and the disruptive effects of interrupting ongoing tasks. McFarlane (1997) refers to task

interruption as a process of coordination between human and machine. To support this coordination workstation, designs must include software that accounts for task interruption and subsequent user refocusing. The MMWS alleviates short-term interruption effects by:

1. Providing low-workload task reaccess using multiple screens
2. Keeping relevant information together for the task without user burden
3. Providing visual cues of changes and highlighting of information changed since the user last checked the information

Another important design requirement is the method of design for interruption alerts that change user task and attention focus. Software methods must be developed that consider the context of the interruption across multiple events. An event may appear to be important to require an interruption of the user when considered in isolation but not be worthy of interruption when other life-threatening tasks are also present. Thus, the requirement for context-sensitive alerting is present. The design approach of whether to interrupt abruptly or provide more subtle interruption cues depends on mission context and time criticality of the task events, taken in context within the mission focus. This requires interruption in the form of visual, auditory, or haptic cues that inform the user beyond the simple auditory alert buzzer used in many systems today. A multilevel alerting system has been proposed for the MMWS project, allowing a wide range of interruption possibilities (Obermayer, 1998). The proposed system has yet to be fully implemented in MMWS and tested with workstation operators.

20.4.6 Supervisory Control Requirements

The human role working in cooperation with automation is variable, ranging from: (1) task monitoring with hands off to (2) task confirmation at the last procedural step to (3) full involvement through multiple task steps. Task management automation removes much of the user burden of task initiation, and other aids reduce the workload in completing each task procedural step. The degree of user involvement for task supervision may be dictated by task external pacing. With more work time available to focus per task, there is more opportunity for hands-on work, but with less time available there is an increased need for intermittent task focus by way of supervision of the automation. The workstation must easily support both types of work allowing the users to adapt to changes in workload. MMWS provides several important features to aid in visual search and information acquisition during supervisory control tasks. The design requirement is to provide relevant cues for high-level information visual scanning, supporting decisions regarding the need to drill down into detailed information content. The requirements are made more complex by studies that suggest the type of work tasks assigned to the crew member should vary over short periods of time.

Example 20.7 Continuous Skill-Based Tasks and Alertness Neerincx (1999) reports that just 10 minutes of continuous skill-based performance tasks can decrease performance. As workstations and automation can be made more capable, a newer design challenge emerges to vary tasks in ways that maintain crew alertness throughout the typical 6-hour watch session.

20.4.7 Ergonomic Requirements

The comfort and safety of the system operator is a critical design requirement for the watchstation design. The console display pedestal must provide a comfortable work environment for body statures ranging from the 2.5 percent; female through 97.5 percent male size. Visual and reach envelopes for displays and touch-screen interaction must be considered such that the user can rest the elbow on the desktop surface comfortably and reach the majority of the display surfaces. Input devices must consider the motion effects of sea conditions and the possibility that the watchstation could be moving with a rough sea state. Another important consideration affecting the pedestal design is team arrangements and the ability for team members to see each other. The taller, bulky consoles of today prohibit face-to-face interactions and force arrangements of crews into rows and aisles of equipment. Ergonomic touch, reach, visibility, and team interaction requirements led to an MMWS design approach that accommodates the physical statures listed, provides controls suitable for various sea conditions, and allows close-proximity team interactions.

20.5 DYNAMIC TASK REQUIREMENTS

Many of the static or qualitative requirements for user task support discussed in the previous sections do not account for the *dynamic* stages and processes involved in task completion, and the effects of time and job pacing on task progression and the human information processor. Dynamic task properties include task and job attributes that change over time due to the rate of information change, the loading of tasks, and the context of multiple competing tasks occurring in the same time continuum. User qualities of fatigue and alertness change over time also. Dynamically varying data sets and information support tasks have a time context within the changing tactical environment. The degree to which the system designers can capture the context and relevancy of the task information with respect to current operations could make systems more responsive to the users' current needs. This section discusses these important qualities of tasks in a task-centered design approach from the perspective of task timing and the dynamic life cycle of tasks.

20.5.1 Dynamic Task Timing and Pacing

Frequency and repetition of task events within the job context play a role shaping the system design concepts. Task pacing, vigilance loading, and multiple task timing are important factors requiring design support.

Externally Paced versus Internal Pacing Tasks that are externally paced cause work-induced stress. The tactical work environment creates this stressful pacing since system users have no control over the pace at which the enemy or other tactical entities decide to operate. By nature, the goal of an adversary is to overwhelm the opponent. But designers can consider design options to mitigate the effects of external task pacing. For example, tasks can be designed such that their workload could be distributed across team members if it increases to unacceptable levels. Workload distribution is prohibited in today's systems due to strict assignment of tasks with specialized operating modes in each workstation. The specialized training of today and lack of ability to flex workload decreases survivability, given that removal of key consoles or positions offers no

replacement. System tools and architectures for information delivery that allow for distributed workload and for assignment of any task at any station maximize survivability across the entire ship. These design properties associated with workload distribution should be factored into ship-level survivability and failure mode analyses. In MMWS the task management system is designed to reduce externally paced workload on any given individual by allowing tasks to be distributed among the team members. Voice and auditory information tasks are often externally paced, and the design can support increased user control over the pacing of tasks through digital storage of audio, thereby allowing the task to become internally paced.

Vigilance and Situation Awareness Vigilance tasks over periods of time create boredom and induce fatigue. The designer should consider system support in eliminating vigilance tasks wherever possible. A warfare tactic sometimes used involves human vigilance and perception. An adversary may repeat training exercises for many days or months, until the exercise becomes the perceived "norm." When an attack is planned during a training exercise, the initial reaction is that "it's another training exercise." Then the initial stages of attack are less perceptible from the routine exercises, which evolve to not be of high interest. The MMWS design focuses on system support to reduce vigilance workload by automatic detection and triggering of tasks. The design attempts reduce or eliminate errors and risk emanating from situations where human detection is the sole method for beginning a task process. The design will need to support human manipulation and editing of the thresholds and external conditions desired for task triggering. Given the complexity of these external conditions, the interface design will present a challenging problem.

Long- and Short-Term Work Task time frames may vary from seconds to minutes to hours. Task times will vary across mission domains such as air and land attack. Some tasks may be time-on-target, requiring scheduling of task goals at a specific time in the future. The design should consider the varying time properties of tasks and require the system to support multiple active tasks with different time frames—with the ability to quickly move between these tasks to update situation awareness or to easily refocus attention on a task product.

20.5.2 Dynamic Task Life Cycle

Another important set of task properties relate to the task life cycle. In the previous section we spoke briefly of the concept of task initiation, with respect to task management work activities. Definition of additional states in a task life cycle are necessary to fully support the work process through the life cycle. The life cycle phases in a task may be defined as follows:

Initiation: The task supports part of an ongoing mission activity. The task processing is invisible to the user and only seen as part of a list of possible tasks that might occur or that are planned for in the future.

Activation: The task goal becomes active and requires servicing by the user or system.

Assign: The task is assigned to human(s) or system (e.g., if automated).

Execution: A task product is prepared or response activities are conducted.

Completion: The product is finalized, delivered, and delivery is confirmed. Task events or activities are completed and results are confirmed. The instance of the task is complete. The general task then goes into the same pending state as during the initiation phase.

Retire: There is no longer any anticipated near-term need for the task, such that any processing or system activity associated with it can be ended.

Events monitored while progressing through the life cycle can trigger decision support tools or "behind-the-scenes" automation and services. It is important to recognize that today's tactical system designs focus almost entirely on execution. In automated doctrine systems such as found in the AEGIS ship system, we find some predefined activation facilities based on tactical events. But many of these system services are seldom used as they only apply to tactical events that seldom occur.

These phases of task activity generate requirements to support the human processor's activity including:

Initiation: Informing the human that a task goal has become active and that work is scheduled to be done.

Orientation: Guiding the human visual and auditory processors to and through the information required to process the task, such as reviewing a proposed task product and the amplifying information to support the product.

Decision: Supporting the decision process for one or several task steps ending in approval, delay, or canceling of the task product and task goal. Providing the summary information, basis for results, recommendations, etc. for the task decision.

Execution and Product Delivery: Final preparations or confirmation of task products and approval of their delivery or execution.

Confirmation: Clearly defined indication that the task process is initiated or products are now sent and delivered.

Transition: User decision process to move to another task activity and selection by the user of the next task activity to focus current attention.

These phases of task processing can be compared to the command and control (C^2) process models such as the observe–orient–decide–act (OODA) decision processing loop as defined by John Boyd or Lawson's C^2 process model (see Allard, 1996). Lawson's model—sense–process–compare–decide–act—more closely represents MMWS functions but still is incomplete with respect to defining confirmation and transition. The designer is faced with the challenge of determining what system support affords the human information and decision processing in *each* of the process steps (e.g., what can the human do reliably and what can automation do?; how do both cooperate to achieve task goals?). While some designers might interpret "observe" or "compare" as an inherently human function, in MMWS the human first observes information that has been "sensed," "processed," and "compared" (as in Lawson's model) to the desired state of tasks, supported by automation in the form of task rules and heuristics.

User Decision Paths There are several decision paths the user may take after initial information processing. The task completion process may vary according to workload and task risk or mission criticality. If the user understands the task, product, and goal, and

judges the quality of the product to be sufficient, the user may move to final execution and satisfaction of the immediate task goal. However, the initial decision "action" may be a decision to spend further dwell time on the information to decide whether it requires further processing. Several factors may affect this decision. The "newness" or novelty of the task in the current work context will likely affect task processing strategies. A new task usually warrants more investigation by the user and longer orientation times. Workload and task priority will also drive the decision strategy for orientation and review of task products. A familiar and repeated task will require less orientation. The user strategy for familiar and repeated tasks will lean toward a "naturalistic" process of reviewing the task information and quickly confirming the draft task product and deciding if the task is both timely and required in the current mission context. The expert user will recognize that the pattern of information and results drafted by the system for a task meet the current requirements either for approval, delay, or cancellation. Task risk is another important factor in the user's decision process on how much attention and cognitive processing to allocate to the task. In MMWS the initial orientation phase involved a visual review of a task draft product, the context of the task, including user judgment on whether the task is to be completed, delayed, deleted, or shed (passed to another team member).

Confirmation The process step of "confirmation" is omitted from the C^2 process models but in MMWS the requirement was addressed to provide feedback to the user about task processing beyond the immediate task execution action. The warfighter's visual and aural senses must receive immediate confirmation (visual or auditory) that the system is executing the task commands. Confirmation information of task completion must also be persistent (able to be revisited) to guard against possible degradation of confirmation information within working memory. This loss or interference of confirmation information retrieval could lead to task duplication. This requirement is addressed in the design of the response planner/manager display in MMWS.

Transition Task transition is critical but not accounted for in legacy system requirements nor addressed in the C^2 models by Lawson or Boyd. Delays or inefficient decisions during this stage of processing can decrease performance reaction time on critical mission tasks. Without system assistance the user is forced into an intertask workload demand to recall mission activities in progress, decide whether to scan for new tasks or recall a previously incomplete task, and then gather information to check the status and relative importance of events to prioritize the next task action. There can be search paths and strategies that lead to diminished results and further waste workload. St. John and Osga (1999) showed that transition strategies for selection of tasks could be improved by providing task priority selection cues to users for selection between mission and time-critical tasks.

20.5.3 Task Management Requirements

A goal of the system design is to match the dynamic task life cycle to human information processing and decision requirements. These must be matched for each of the major life-cycle phases in task processing. Table 20.2 shows the major stages in the task life cycle paired with human information requirements. The requirements in this table are repeated in Table 20.4, with design options listed to address these requirements. The process of "task management" addresses a set of requirements that afford the focus of user attention

TABLE 20.2 System Requirements Related to Task Life Cycle

Software State	Mission State	Human State	System Requirements
Automation initiated to detect task trigger events. Access provided to manually trigger tasks.	Task pending as part of a planned mission process (e.g., air defense). Ship on-station, with orders, assigned mission role and responsibility.	• Assigned role in team with pending task responsibilities. • Aware of pending tasks and goals. • Developing SA relative to mission goals and responsibilities.	• Present task plans. • Assign tasks to match user roles and responsibilities. • Provide practice and rehearsal functions. • Monitor events for task triggers.
Activate task processing and produce draft products and information sets to explain products.	A. Task activated due to mission events and/or scheduled time. B. Task activated by human decision.	A. Same as above—awaiting information cues. B. Decide to manually initiate task or react to verbal orders to activate.	• Calculate task information and draft products. • Provide controls to easily launch task for manual activation.
Assign task: Provide information on task to assigned watchstation.	Task goal is active and pending assignment to individual or team based on naval operational rules and procedures.	• Become aware of task goal being activated. • Discontinue previous activity to launch task. • Launch task information presentation.	• Determine which team member gets task assignment (by preassignment, current workload, or team leader). • Provide appropriate visual and aural attention cues to guide user to task launching.
Launch and execute task	Task goal awaiting execution and completion.	*Initiation (launch) task* • Become *aware* of task goal being activated. • Suspend or end other task activity to start task. • Launch task information presentation. *Orientation*: Gain SA for task. *Decision*: to execute, delay, cancel task. *Execution*: Perform actions appropriate to satisfy task goals.	• Provide controls to launch task. • Provide flexible methods to account for various user processing strategies. • Supervisory displays—display for quick assessment. • Summarize information to orient user and speed. • Provide decision support and produce "draft" task products for review execution.

			• Task product summaries—packaging for execution, delivery appropriate for automation approval level.
A. *Suspend (delay) task* B. *Complete task* C. *Cancel task*	A. Mission timing or system constraints allow only partial completion. B. Task goals are met and products delivered. C. A task is triggered but in current mission context is not needed.	A. *Suspend* task after partial completion due to mission, timing, resource, or system constraints. Store task awareness in short-term memory (STM). B. *Delivery*: Complete final step of task product delivery. Store task awareness in STM. C. *Cancel* task because the product and result of task is not currently required to meet mission goals. Store task awareness in STM.	A. Record state of task when suspended. Continue task processing if appropriate. Monitor task state and inform user if appropriate when to reengage task. B. Conduct final task processing and provide feedback that task executed properly—message sent, product delivered. C. Provide function to cancel a task and remove it from the display, and record in any historical task documentation that task was canceled by user.
A. *Awaiting task execution* B. *Awaiting task trigger events*	A. New tasks are pending execution. B. No current mission response activities. Information changing.	A. *Transition*: Pause and rest or decision to select another task. B. User proceeds to update SA and mission monitor tasks, await new tasks, or look for manual initiation opportunities.	A. Provide direction and cues to the next most important task to be executed. B. Provide general SA information, update on important events since last SA check.

TABLE 20.3 Key Task Characteristics Related to Task Management Requirements

Task Characteristics: Tasks...	Design Requirement: System Should...
May have definable start/stop schedules.	Monitor concurrent loading and make schedules visible to user.
Have definable goals.	Monitor progress toward goals; offer assistance if needed; report progress toward goals; allow user to modify or create new goals.
Are grouped as parts of overall job role.	Provide visual indication of task assignments and task "health."
May be user and/or system invoked.	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Have information and control requirements.	Minimize workload to access info. or controls.
Are mission or computer control focused.	Provide full top-down task flow and status for mission tasks with consistent, short multimodal procedures.
May involve varying levels of automation from full manual to partial to fully automated.	Provide visual indication of automation state with supervisory indicators.
May require one or many databases.	Do not require the user to know which database for any task. Direct queries automatically.
May require one or many software applications.	Require user to know the tasks, not multiple applications; integrate information across the job versus application.
Will require attention shift between multiple tasks in foreground and background (parallel).	Provide attention management and minimize workload to shift between task focus.
Have definable cognitive, visual, and motor workload components.	Use task estimates for workload distribution and monitoring among crew members.
Will likely be interrupted.	Provide assistance to reorient progress and resources to minimize working memory load.
Should be consistent from training to field.	Provide consistent terms, content, goals throughout.
Will evolve as missions, systems evolve over the life cycle of the ship.	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.
May be individual or collaborative.	Support close proximity and distant collaboration via visual and auditory tools.

throughout the task life cycle. Endsley and Garland (2000) indicate that, in "general aviation" pilots, task management, including ability to accurately assess the importance and severity of events and tasks is an important component of level 2 SA (see Section 20.4.1). In MMWS a design focus on task management requirements led to definition of task characteristics (see Meister, 1985) and projected (estimated) characteristics for a future naval system as shown in Table 20.3 (Osga, 1997). The need for visual feedback and guidance for task management listed in the right column of Table 20.3 led to the development of a task management support function in MMWS.

TABLE 20.4 System Design Related to Task Life Cycle

Software State	Design Approach Examples	Human State	System Requirements
Automation initiated to detect task trigger events. Access available to user to manually trigger tasks.	• Summary displays of task plans by track (mission focus). • Summary of tracks awaiting task processing. • User task assignments. • Tools to support task planning and practice.	• Assigned role in team with pending task responsibilities. • Aware of pending tasks and goals. • Developing SA relative to mission goals and responsibilities.	• Present task plans for user inspection/editing. • Provide practice and rehearsal functions • Monitor events for task triggers.
Activate task processing and produce draft products and information sets to explain products. *Assign Task*: Provide information on task to assigned watchstation.	Access methods (VABs, voice, menus) for manual task launch.	A. Same as above. B. Decide to manually initiate task or react to verbal orders to activate. • Become aware of task goal being activated. • Discontinue previous activity to launch task. • Launch task information presentation.	• Calculate task information and draft products. • Provide controls to easily launch task for manual activation. • Determine which team member gets task assignment (by pre-assignment, current workload, or team leader). • Provide appropriate visual and aural attention cues to guide user to task launching.
Launch and execute task	• TACSIT icons, TM icons, track popup menu, RPM task bar. • Information set design. • Color coding standards across ID and information assessments. • Attention cues such as track fill or no-fill. • Task "draft" products. • Recommendations for best task solutions.	*Initiation (launch) task* • Become *aware* of task goal being activated. • Suspend or end other task activity to start task. • Launch task information presentation. *Orientation*: Gain SA for task. *Decision*: to execute, delay, cancel task. *Execution*: Perform actions appropriate to satisfy task goals.	• Provide controls to launch task. • Provide flexible methods to account for various user processing strategies. • Supervisory displays—display for quick assessment. • Summarize information to quickly orient user. • Provide decision support and produce "draft" task products for review execution.

(*continued*)

TABLE 20.4 (*Continued*)

Software State	Design Approach Examples	Human State	System Requirements
	• Concise product displays with "one-touch, one-command" delivery methods. • Redundant point or hands-on-keypad/trackball methods. • Communications setup for task in case voice conference required.		• Task product summaries—packaging for execution, delivery appropriate for automation approval level.
A. *Suspend task* B. *Complete task* C. *Cancel task*	A. Brief summary indicator of task progress. Indicator of when to return to task if predicted. Attention cues to return to task. B. Clear and concise feedback of task successful completion. Confirmation of final product delivery. Storage of task instance for future reference. C. A function to delete task is provided with the task product or task icon.	A. *Suspend* task after partial completion due to mission, timing, resource, or system constraints. Store task awareness in short-term memory (STM.) B. *Delivery*: Complete final step of task product delivery. Store task awareness in STM C. *Cancel* task because the product and result of task is not currently required to meet mission goals. Do not store in STM.	A. Record state of task when suspended. Continue task processing if appropriate. Monitor task state and inform user if appropriate when to reengage task. B. Conduct final task processing and provide feedback that task executed properly—message sent, product delivered. C. Provide function to cancel a task and remove it from the display, and record in any historical task documentation that task was canceled by user.
Transition A. *Awaiting task execution* B. *Awaiting task trigger events—SA maintenance*	A. Task instance icons on task summary display. Concise listing of most important tasks on the queue. Track instances shown (a small window per track) within a task type, peripheral task indicators (near TACSIT window) shown across task types. B. Provide access and cues to SA updates and important information changes.	A. Pause and rest or decision to select another task. B. Proceed to update SA and await next task assignment.	A. Provide direction and cues to the next most important task to be executed. B. Provide general SA information, update on important events since last SA check.

20.6 DESIGN BY TASK REQUIREMENTS

The previous sections described how HSI provided assistance to the MMWS project using a task-centered approach. In particular, the HSI process focused the designer on providing user support through the task life cycle, with the critical contribution of establishing both static and dynamic requirements for the four major task categories (mission, human support, work management, and workspace computer management and control). These sections covered the first major component of the task-centered design (TCD) process—establishing HSI requirements. This section and the next cover the MMWS experience in the second major component of the TCD design process—creating TCDs.

The creation of design concepts to address the requirements for MMWS included several key inputs:

1. *Experience and Lessons Learned for Similar Systems with Similar Tasks* Previous research projects with similar tasks provided design input by supplying HCI tool "components" that supported computer interaction tasks (Osga, 1995). Decision support study results provided a basis for decision support methods (Morrison et al., 1997).

2. *Innovation and Creative Design Solutions* The general philosophy of designing the watchstation to support task goals (e.g., "task-centered" design) was a central theme for innovation within each critical task area. The dynamic task life cycle, as described in previous sections, is supported by system functions that account for human capabilities in visual search, cognition, memory, and training issues.

3. *Traceability of Requirements to Design Results* Requirement lists were generated and used to focus concept design toward methods to address these requirements. Traceability is particularly critical in new design, when management seeks an explanation of what requirement the design addresses.

4. *Iterative Testing of Design Concepts with Users* All requirements identified were not addressed in the initial concept design. Iterative testing was a critical part of the design methodology and focused the results on products that worked with the navy user population.

Example 20.8 Rapid Prototype Refinement of Design Requirements The design concepts were captured in task description documents and design descriptions. They were then turned into working models using the Macromedia™ Director authoring software. This software provided a rapid prototyping method to support usability testing. A parallel development team created a JAVA-based software version, as requirements and design were further stabilized. In this manner the Rapid Prototype version consistently fed design requirements to the JAVA programming team as usability tests were completed.

A summary of the MMWS display design is shown in Figure 20.2. The four-screen watchstation is shown with an "information set" assigned to each of the top three screens and the bottom center screen containing the Task Manager display with other windows. Each of these components is described in further detail together with the requirements that were addressed with the design features. This description includes how the design addressed the requirements of the task life cycle and decision support, attention management, task management, user navigation, and ergonomics.

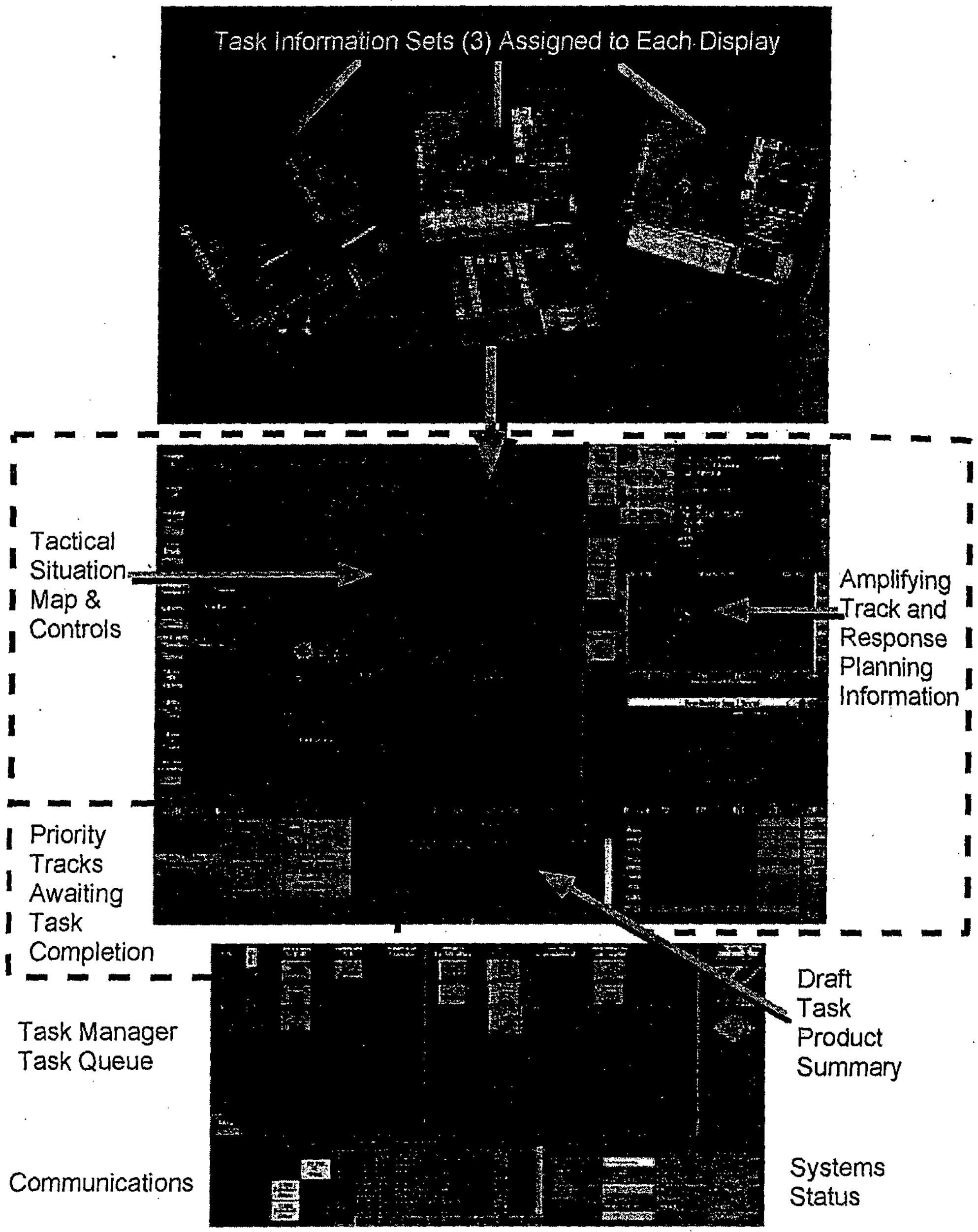


Figure 20.2 MMWS display layout and task information sets.

Table 20.4 summarizes many of the design properties of MMWS in relation to user support through the stages of the task life cycle. Each of these task phases and design attributes are discussed in further detail in the following sections.

20.6.1 Task Initiation Design

Task *initiation* is defined as the initial processing of task triggering information and ends with the start of the next phase of calculations for draft task products. This processing of

task information is invisible to the end user. The user is brought into the loop at the end of the initiation process, when the system identifies the presence of a task to the user.

The following task initiation requirements are addressed by various design attributes of the watchstation.

1. *Present Task Plans for User Inspection/Editing* The MMWS presents task plans using several views: (a) Top-level iconic view of all tasks, (b) graphic view of assigned tasks (coded by assignment to the user or automation), (c) graphic view of plans within a task (detailed by track if appropriate), and (d) iconic view of tracks within a task focus area (sorted by simple ID priority). The Task Manager display column headings (see Fig. 20.3) shows the current tasks assigned to the warfare team. The response Planner/Manager display was designed to allow user inspection of task plans (see Fig. 20.4).

2. *Provide Practice and Rehearsal Functions* The requirement to support task response planning and practice was not addressed in the current MMWS design, and the plan was fixed for the test scenario operational area. This design did not allow any flexibility in editing task plans during the mission simulation. This requirement allows the user to cognitively rehearse mission responses and adapt the responses to different operational areas and conditions.

3. *Monitor Events for Task Triggers* The MMWS simulation was designed to monitor simulated shipboard databases for events and information changes, using rule-based event triggers. Tasks are initiated in response to predetermined events, using simple mechanisms and rules. The task description documents generated for each task contained details of prescribed task triggers (Osga et al., 2002b).

Task Initiation Design Summary Task initiation requirements play an important part in the life-cycle task process. If the user or system does not initiate a task, the goal is

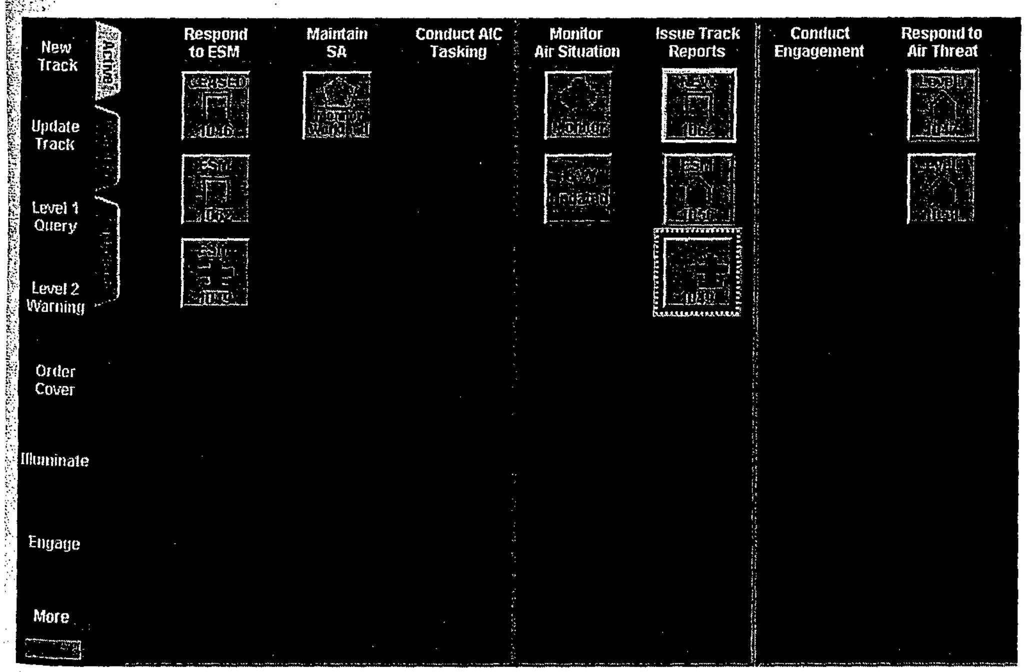


Figure 20.3 Task management icon list display for air defense tasks.

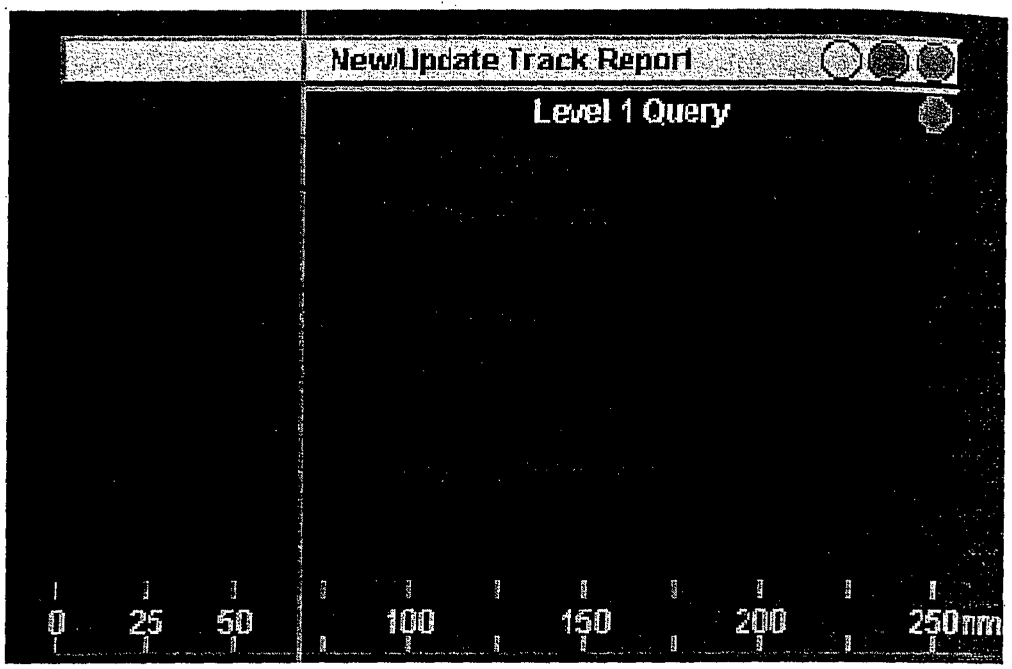


Figure 20.4 Response planner decision support tool.

not obtained. These requirements were addressed in the MMWS prototype by using embedded task triggers for all air defense warfare (ADW) tasks within the scope of the current test mission problem. The triggers were fixed and not editable by end users, but they followed a battle response plan agreed to by SMEs as reasonable and following accepted practice with fleet methods for the scenario. Task inspection information and response plans were provided using several iconic and graphic display formats.

20.6.2 Task Activation and Assignment Design

Task activation may follow initiation and starts the process of finalizing the task product and meeting the immediate task goal. Activation can be either manually performed by a human action or automated in a fielded system. In MMWS software and design, activation was manually performed in one software version and had automatic assistance in a second version. Requirements during activation and assignment are as follows:

1. *Calculate Task Information and Draft Products* When a task was triggered, software mechanisms were set in motion to create task products. These products included draft messages such as new/updated reports, queries, and warnings. The design philosophy was that the system would attempt to create a "draft" product in best format possible, allowing for user inspection and approval of the draft. The current software design did not address user editing of draft products. Some tasks did not involve products for delivery, but for inspection, such as an update to operational orders or rules of engagement that required user cognizance. The product was formatted with text changes colored since the last inspection performed by the user.

2. *Determine Which Team Member Gets Task Assignment* The initial ADW design did not address assignment by workload. The tasks were preassigned as designated by SMEs' judgment of appropriate assignments. The limiting factor on task assignment was related to the monitoring of ship audio circuits. The various circuits needed an assigned operator to monitor replies from external sources—other ships, aircraft, etc. The assignment of a single person to a single circuit work strategy significantly limited workload distribution and task assignment for tasks associated with communications events. This also prohibited the distribution and leveling of workload across the team as originally planned for MMWS. While there was considerable controversy among the MMWS design team as to how communications might be handled in the future, the limitation of workload distribution represented a worse-case design condition basis that communications external to the ship would be handled using today's voice technology. Members of the design team could envision digital messaging and transfer information to and from the ship in ways that would lessen the workload restrictions for some types of messages such as "new" or "update track" reports. Other messages such as directions to aircraft or warnings to aircraft were determined to require an operator dedicated to getting the replies from the external aircraft. The task demands for external communications must be given serious consideration in determining workload distribution aboard future ships.

3. *Provide Appropriate Visual and Aural Attention Cues to Guide User to Task Launching* When a task was initiated, three display events occurred: (1) An icon was presented on the task manager (see Fig. 20.3). (2) An icon could appear on the peripheral task indicators if the task was at the top of the queue for that task category. (3) An instance of the task could appear as a small amplifying information summary window in the list of windows for a task category (see "priority tracks awaiting completion" in Fig. 20.2). Aural cues were used in usability studies to represent different task attributes, and it was determined that they did not add benefit to task launching performance while creating unnecessary distraction. Auditory cues were delegated to a supportive role if the task response exceeded a certain time limit and urgency requirement.

20.6.3 Task Execution Design

During execution the users' attention processes are focused on the task requirement when a decision has been made to begin task execution. Task execution involves the process of supporting control actions and decisions relevant to satisfying the task goal(s). Execution includes the user launching the task to populate displays and windows with the task information set, and then the user monitoring or executing the task as appropriate. The final step to execution would be delivery or cancellation of the task product. Execution could also be delayed and then restarted at a future time.

The MMWS design included multiple displays to allow the user to easily time-share display allocation between concurrent tasks without requiring changes to a single display to transition between tasks. The need for task time-sharing varies according to mission demands, and at times of low workload, a single display may suffice. The three displays were considered supportive in a high workload environment. They were also selected and positioned on the basis of ergonomic requirements (see Section 20.4.7).

Example 20.9 Flexible Control Methods to Launch Tasks To aid in quick performance reaction and reduce visual search, redundant methods were provided to launch tasks. These methods were based on user cognitive and visual strategies envisioned for task processing.

Several methods, including task icons, task bars, and pop-up windows, were provided to launch a task. Several of these task launch methods provided a similar support strategy to launch a sequence of task events allowing the operator to maintain visual focus on a single display area to accomplish a sequence of tasks. These methods allowed the user to work within a task type, "task family," or to move between task families and types.

Quick assessment and flow through task processing is done by making visual search and visual work flow through the task efficient. Visual work must flow within a display and flow across displays. In the design of display layouts there are no perfect answers, but instead there are many layouts that could foster effective task flow. The MMWS design supports a user strategy of continued work within a task (single display), quick sampling of the larger work activity (Task Manager and three displays), and switching rapidly between tasks (visual shift to primary displays). The workload induced by a display visual shift, combined with common formats and common placement of similar information (such as task products), would be less than that required to access, remember, and locate commands/menus to navigate between tasks. This simple visual shift between tasks should be less disruptive to cognitive processing of higher level mission activities.

Example 20.10 Supervisory Displays There are several supervisory "layers" provided in MMWS design to aid in fast assessment. The highest layer is across an entire display, where differences in color provide visual cues for conflicting or homogeneous information on ID. Supervision requires visual and cognitive processes to first sample information and second to decide when to dig deeper into a task processing. A key information issue is the urgency and mission-critical nature of the task or information. Information that is neither urgent nor mission critical is left for future processing while urgent or critical information is given attention. The first layer of user processing is by position and color. For example, position coding has task family positions constant in the Task Manager (TM) display and task icons placed and coded on the TM list according to urgency; whereas color coding is used to aid in quick scanning such as for conflicting ID information by using multiple hues. Other design methods include:

- *Summarize information to quickly orient user.* Kellmeyer and Osga (2000) report that the Basis of Assessment window (see Fig. 20.5), with its color coding and consistent summary of ID information, is one of the most useful information summary displays on the MMWS.
- Provide decision support and produce "draft" task products for review before execution.
- Provide task product summaries—ready for execution, delivery appropriate for automation approval level.
- If task is suspended, record state of task when suspended. Continue task processing if appropriate. Monitor task state and inform user if appropriate when to reengage task.
- Conduct final task processing and provide feedback that task executed properly—message sent, product delivered.
- Provide function to cancel a task and remove it from the display and record in any historical task documentation that task was canceled by user.

20.6.4 Task Transition Design

Task *transition* design includes support for decisions about work strategy and direction of attention toward available task opportunities. Transition involves a change of immediate

Figure 20.5 ID basis of assessment display. Right side of window shows ID history parameters and colored bars indicate change over time. Left side shows current threat positive for selected track.

user focus from a specific task goal toward identifying the broader scope of task goals to be accomplished, followed by a decision whether to continue sampling for task opportunities or to begin to work to accomplish a specific task goal.

1. *Provide Direction and Cues to the Next Most Important Task to Be Executed* Several visual cues were used to provide information on the remaining tasks to be executed. The coding methods are shown in Table 20.5. On the tactical display window, symbols were filled if an incomplete task was remaining and unfilled if no tasks were pending. Thus, if New Track Report task was currently selected, all filled symbols shown were those pending a new track report. If Monitor Air task was selected, all pending tasks were shown for suspect and unknown tracks. In the periphery of the tactical display the task icons were listed showing the top task in each task family, and the Amplifying-Information windows showed a sorted list of tracks within the selected task. Table 20.6 lists the triggers and

TABLE 20.5 Visual Cues to Aid Task Transition

Display Location	Type of Visual Cue	Comments
Tactical situation map	Filled symbols	Indicate task in queue awaiting processing. If monitor air situation then only suspect or unknown symbols with pending tasks filled.
Tactical situation display peripheral area	Task icon	Show top task icon from each task family.
Tactical situation periphery	Amplifying information windows	Show sorted windows for top 7 tracks in the selected task family.
Response planner/manager (RPM)	Show next suggested task with highlighted text on task bar.	A circle appears on the bar if someone on the team activates a task and it is in progress.
Task manager (TM)	Task icon with time or urgency color border on the task icon.	Task icon border colors were used. (See Table 20.6 for coding rules by task type.)

TABLE 20.6 Visual Cues for Task Urgency/Latency

Task Type	Visual Cue Trigger	Type of Cue (lower to higher urgency shown)
New track report	2 minutes—no response	Yellow border on task icon
Update track report	3 minutes—no response	Orange border on task icon
I&W updated	5 minutes—no response	Red border on task icon
ATO updated		
ROE updated		
Level I query	Longer range from ownship	Yellow border on task icon
Level II warning	Medium range from ownship	Orange border on task icon
	Close range from ownship	Red border on task icon
ESM tasks	No cues used	No colored borders used
Maintain workload		
Monitor air situation		

visual cues associated with tasks that had a late response or an increase in urgency due to the position and heading of the track in relation to friendly ships.

2. *Provide General Situation Awareness Information, Update on Important Events Since Last User Information Check* Within the limited air defense task domain studied, several tasks were included to provide an update to situation awareness and changing information. The system provided updates to the indications & warnings (I&W) status, air tasking order, air warfare situation representation (SITREP) report, ship equipment status, and rules of engagement (ROE) as information changed for these documents. Information that changed since the last user update was shown using an alternate color in the window.

20.7 SPECIAL DESIGN QUALITIES

There are a number of design qualities stimulated by the HSI process that were integrated into the product such that the overall design produced shows a strong focus on HCD qualities including:

- Design for decision support
- Design for attention management
- Task manager design concepts
- Design for user navigation and selection
- Design for user ergonomics

20.7.1 Design for Decision Support

The decision support design principles used in MMWS were:

1. Bring the information to the decision and summarize it.
2. Clearly show any ambiguity or conflicting information with regard to the decision.
3. Provide assistance in the timing, planning, and scheduling of decisions.

TABLE 20.7 Coding Methods Used in RPM Display for Decision Support

Coding for task name on task "bar"	
	Gray text—task not yet recommended for this type of track and its kinematics.
	White text—task may be recommended at future point if track maintains same ID and same kinematics.
	Black text—task is completed already if task bar is white.
Coding for task completion status	
	Black bar—task completed.
	White bar—task has been created (system or operator).
	Gray bar—task not initiated.
Coding to keep record of occurences of task for track	
	Open circle—task currently in process or pending.
	Green circle—task has been completed.
	No circle with white bar—indicates that the task was probably deleted by an operator.

An example of these design principles were shown with the information sets that provide the task information for each task goal, with color-coding used to show ambiguous or conflicting information related to the track ID involved in the task decision. Also, the TM and response planner manager (RPM) displays provided work strategy decision support mechanisms. Further, visual coding rules were used in the RPM display to provide decision support information on work strategy to the user as summarized in Table 20.7.

20.7.2 Design for Attention Management

Attention management is the process of system support to guide human resources such that those resources are allocated in an efficient manner to the most critical or urgent task activities. In situations where no time-urgent or mission-urgent tasks are in the queue to be done, attention should be guided toward information relevant to pending and future task goals. Attention management should be handled carefully, due to issues discussed earlier concerning task interruption. In MMWS, a layered approach to management included (1) visual cues and (2) alerts (visual and auditory) that supplement the visual cues. The primary visual cues guide work flow and resource allocation between and within tasks. Specific cues guide attention within a task. Many of these visual cues have been presented in earlier sections on design for task initiation and execution. In addition to capturing visual and auditory channels when needed, the system must foster smooth and efficient flow toward completing the work activity and then through task transition. The following sections discuss two attention mechanisms in MMWS: task prioritization within the task management functions and alerting mechanisms. Two examples are presented.

Example 20.11 Task Prioritization Task prioritization schemes were proposed but not fully implemented in the MMWS software during the project time frame. A priority scheme was proposed with four levels ranked from highest to lowest priority: (1) mission critical and time critical; (2) mission critical but not time critical; (3) time critical but not mission critical; and (4) neither time critical nor mission critical. This task prioritization scheme was not effective by itself, and another variable came into play that did not allow preassignment of a "rank" to a task type. The object or track involved in a task could make that task change between levels of

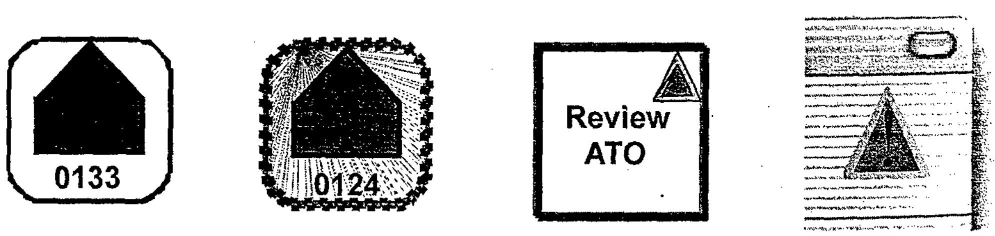
mission or time criticality. Thus, a new track report for a track identified as a commercial air at some distance was level 4, while the same report for a suspect closing to the battle group might be level 1. Then, a more elaborate prioritization was proposed based on various track ID parameters (Hildebrand, 1999). The detailed prioritization methods were not implemented in the current MMWS software, and a simple scheme of first-in, first-out was selected with the most recent task instance shown at the top of the display for each task group. As expected, in comments from users following tests, users did not approve this simple prioritization method. Further research is warranted on best methods to prioritize and rank tasks, including methods on how to update the task priority rankings as these priorities change in real time.

Example 20.12 Attention Management Cueing Methods Attention cueing supports the process of bringing the user's attention to critical issues or problem tasks. Cues were described earlier to guide task progress and transition. Other cueing support was provided to indicate late or delayed tasks and information changes within tasks. The cues were numbered from low to high, ranging from a low amount of visual and auditory stimulus to progressively higher amounts of stimuli. Figure 20.6 shows the visual appearance of several graphic cues. The first and primary-type visual cues notify the user of task initiation and presence, with icons and visual indicators. Higher levels of cue stimulation add additional visual cues in a change of color for the TM icon border. These cues were time-based and appeared within a certain period after no response for a presented task. Higher intensity cues also involved the use of audio cues and blinking of the standard alert icon (a small triangle). The icons appeared in static form as shown on a button or window as shown in Figure 20.6 and then could become blinking after no response for a given period. Lower priority alerts could be delayed if higher priority alerts were present. The relative priority of multiple alerts across tasks becomes an important issue when workload increases.

20.7.3 Task Manager Design Concepts

Design concepts related to task management requirements are listed in Table 20.8. Many, but not all, requirements were addressed in the current design.

Task Manager Summary Window Format Design In order to address requirements related to depiction of task state information, formats were designed to depict tasks currently active in the work queue. Early concepts addressing air defense task progress



TM Icon – Normal Appearance | TM Icon – Delayed Response with altered Border | Button w/ Alert | Window with Alert Icon in Corner

Figure 20.6 Examples of visual alert cues (low priority) used in task manager icons, buttons, and windows.

TABLE 20.8 Key MMWS Design Concepts Related to Task Management Requirements

MMWS Design Concept Basis	Design Requirement
RPM—individual threat response summary. TM display—composite workload and task icons.	Monitor concurrent loading and make schedules visible to user.
RPM—range based, single threat summary. TM display—task summary display. No user modification in current design.	Monitor progress toward goals; offer assistance if needed; report progress toward goals; allow user to modify or create new goals.
TM display and workload indicators.	Provide visual indication of task assignments and task "health."
TM display—task assignment summary. MMWS context and event monitoring to support task initiation.	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Multiple display surfaces—maximize visual work space (within 5–95% reach envelope for touch).	Minimize workload to access info. or controls.
TM expand/contract task list and task filters.	Provide full top-down task flow and status for mission tasks with consistent, short multimodal procedures.
Earlier TM designs indicated automation type. Removed for ADW when automation was fixed for testing. Added for land attack.	Provide visual indication of automation state with supervisory indicators.
Information sets provide information automatically for task.	Do not require the user to know which database for any task. Direct queries automatically.
Apply consistent procedures across different tasks.	Require user to know the tasks, not multiple applications; integrate information across the job versus application.
Multiple displays allow simple visual shift between tasks. Task priority visual cues. Tasks assigned to columns in similar groupings. Task columns match display assignment.	Provide attention management and minimize workload to shift between task focus.
Workload distribution summary display shows relative loading among crew members.	Use task estimates for workload distribution and monitoring among crew members.
Highlight changed information when task is "dormant." Reminders and notes tied to tasks.	Provide assistance to reorient progress and resources to minimize working memory load.
Consistent task design across multiple tasks.	Provide consistent terms, content, goals throughout.
Task groupings fixed in current design. Future support should provide flexibility.	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.

were created in 1989 and reported in Osga (1995). Design concepts for the RPM display from the TADMUS project were also reviewed (Kelly et al., 1996; Morrison et al., 1997) and from research efforts following TADMUS (Manes et al., 1999; St. John et al., 1999).

The RPM display was used to depict planned response actions in air defense warfare showing task duration and deadlines related to individual air threats. Additional informa-

tion was required beyond the single-threat RPM focus to address task situations with multiple threats and multiple mission activities. The TM display was created to provide a view of all tasks planned or in progress. The TM air defense display format differed for long-term tasks such as mission plans or execution of events that occurred over many minutes and involved multiple steps in their sequence.

Usability testing results (Kellmeyer and Osga, 2000) indicated that visual depiction of time, automation, and deadline with display scrolling on the task manager window were not beneficial during high workload periods. Information concerning task deadlines and schedules was not needed in fast-paced air defense tasks. The users simply wanted to see current work in the queue and process the task as quickly as possible. Figure 20.3 shows the simpler TM display with task icons. Simple icons were found to be sufficient for air defense mission task depiction.

20.7.4 Design for User Navigation and Selection

Two important design features include methods to navigate through task procedures and for selection of objects or functions. Five multimodal selection methods are:

1. *Redundant Touch and Trackball Cursor Movement* The watchstation provided several redundant methods with which to navigate the four-screen work space. Methods employed were touch, trackball for full cursor navigation, and partial navigation with keypad. Gross movements were aided by touch. With this method it was impossible to visually lose the cursor since it would always appear where the screen was touched. Moving the cursor large distances between all screens was easily done with touch. Fine selection movements to select tracks, icons, and other GUI objects were done with either touch or trackball. Selection of tracks was aided by the advanced hooking algorithm (Osga, 1991).

2. *Navigation on Task Manager with Keypad* Navigation on the task manager was also supported by the keypad. The arrow keys could be used to move between task icons on the TM and the ENTER key used to select an icon (or the select button on trackball). The user could proceed through most tasks with one hand on keypad and one on the trackball without ever touching the screens or reaching to hook a track. The default task product window and DONE or SEND function would gain cursor focus at the end of a task allowing the select function on the trackball to be used to complete the task.

3. *Track Search with Keypad* Tracks could be hooked and located using the search function with the numeric keypad. With the NumLock set in the "on" position, the user typed a four-digit number in the keypad. A virtual keypad appeared in the top right corner of the tactical plot that showed what was being typed and on which plot the track would be hooked. When the ENTER function was selected, the track with that number would be hooked. Usability test feedback provided positive results for all the methods used for navigation.

4. *Prehook Selection Methods and Information* Prehook information refers to track information obtained by moving the cursor near the track object, before a selection action is made. A dashed circle indicated the track that will be hooked when a select action is made and shows a small set of summary information about the track. When the select (hook) action is made, the circle changes to solid and other auxiliary windows present the amplifying information for that track. A select action used either the left trackball button or

TABLE 20.9 Popup Menus and Methods

Type of Menu	Method Accessed	Notes
Track context popup	Right trackball button	Cursor near track on map
Map context popup	Right trackball button	Cursor over map—not near track
Track list popup	Left trackball button, depress and hold	Cursor near track
Auxiliary window list popup	Left trackball button, depress and hold	Cursor over an unused part of window—not over button

a tap on the screen with the finger. Dragging the finger or moving the trackball showed the prehook indicator as the cursor was moved.

5. *Function Selection Methods* Methods used to select functions included variable action buttons (VABs) and popup windows including the track contextual menu, tactical situation (TACSIT) map menu, track declutter menu, and auxiliary window context menu. Table 20.9 indicates how each pop-up menu was activated.

20.7.5 Task Procedure Design

The MMWS job design contains a set of repeatable procedures designed such that tasks could be launched by several methods. This approach allows the user to adopt multiple task flow strategies during task transition. The user scans for task opportunities, starts the task using several alternate methods, scans the task products and information sets, and makes a task decision and transition to the next task. Table 20.10 compares procedures for

TABLE 20.10 MMWS Task Procedure Design Summary

Procedure Step	Basic MMWS Method[a]	Enhanced MMWS Method
Scan for task opportunities	Tactical symbol color coding for ID	Color coding and Task manager icons
Start task	Variable action button	Task manager icon Track pull-down menu Tactical display peripheral icon Mini-Amp info: selection (if user stays within same task for repeated tracks) Manual Variable action button
Collect information for task	Visual scanning	Decision support information sets
Task decision	Send order, message, report, or read/comprehend information	Send prepared order, message, report, or read/comprehend information
Task transition	Visually scan and wait	Review next Task manager icon

[a]"Basic MMWS" refers to the version with limited decision aids while the "Enhanced" version contained the full set of decision support aids.

the Basic and Enhanced versions of MMWS. This simple procedural method was able to service many different types of tasks, and training was streamlined due to the consistency across task types.

20.7.6 Design for User Ergonomics

In the spring of 1998, the NEC Corporation began producing flat-panel color liquid-crystal displays with a much wider viewing angle. These displays were selected for an upgrade to the MMWS console configuration. An Elographics guided-acoustic wave touch screen was also selected. Initial foam-core mockups of the MMWS pedestal were constructed to evaluate reach envelopes. When the larger NEC displays became available at a 20-inch size, the design was altered to accommodate them. Three displays were placed in the optimum reach/viewing envelope with adequate resolution and display area to accommodate multiple tasks. A desktop version of the MMWS was used for usability testing prior to construction of the display pedestal. The final configuration is shown in Figure 20.7.

20.8 BENEFITS OF TASK-CENTERED DESIGN

The benefits of the design approach are seen with results from individual and group performance testing (Osga et al., 2002a). Individual and group performance tests were conducted with naval fleet operators. Performance gains were found for both speed and

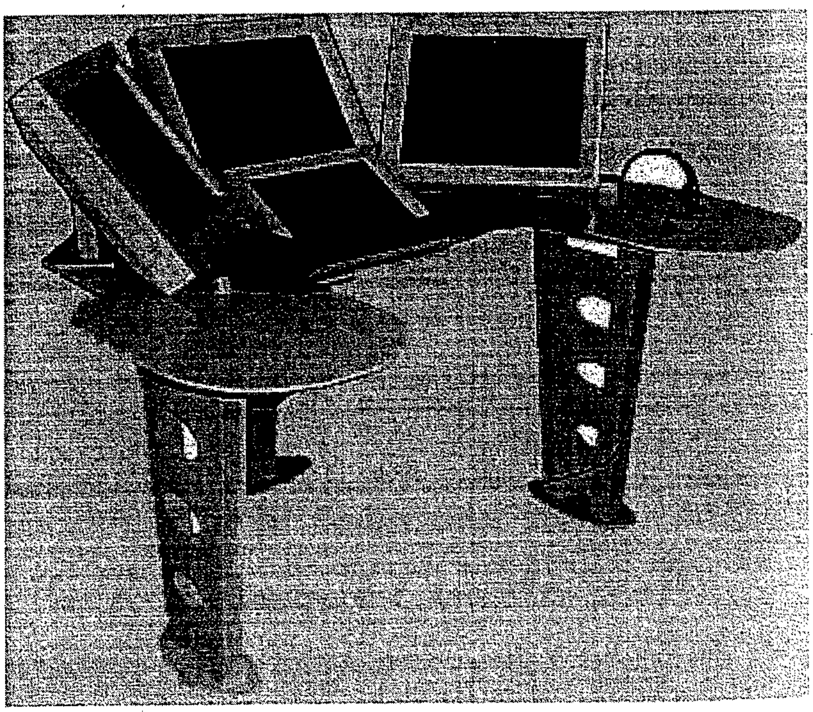


Figure 20.7 MMWS pedestal design.

accuracy with improvement in SA and workload. Training was also simplified relative to the training requirements for similar systems currently in operation.

20.8.1 Performance Testing

A team performance test was conducted comparing shipboard nine-member crews using today's equipment and methods (legacy team) to five-member crews using the MMWS configuration (HCD team). Eight ship crew teams were tested using the scenario aboard AEGIS-class ships at pier-side or in land-based training sites. Six MMWS crews were tested with the basic-capability (BC1) MMWS and two teams with the enhanced-capability (EC2) MMWS. The BC1 version lacked some of the dynamic decision aids, whereas the EC2 version contained the full spectrum of aids. A realistic air defense scenario was prepared containing both low- and high-density track periods to stimulate various levels of tasks required. The scenario test used role players who acted the part of aircraft and other ships in the battlegroup. The role players were positioned in another room separate from the test teams, using voice communications simulating battlegroup operations. The AEGIS teams had eight air defense members plus an air intercept controller, responsible for vectoring aircraft. The MMWS teams had four members with a combination of duties assigned to the smaller crew size (see Fig. 20.8). Teams were instructed to conduct air defense warfare tasks in accordance with the rules of engagement and operational plans briefed during training and as practiced during the training exercised preceding the test. Primary operational tasks were:

- Visually identify (VID) all unknown air contacts within a defined area of responsibility (AOR).
- Escort air contacts from threat country with aircraft-carrier-based friendly aircraft.
- Issue warnings to threat country aircraft.
- Make positive identification of air contacts unable to VID by correlating indications and warning, electronic emissions, profile, point of origin or initial detection, air tasking order, and electronic data received.
- Conduct internal communications and external communications with battlegroup commanders and aircraft.
- Engage in self-defense.

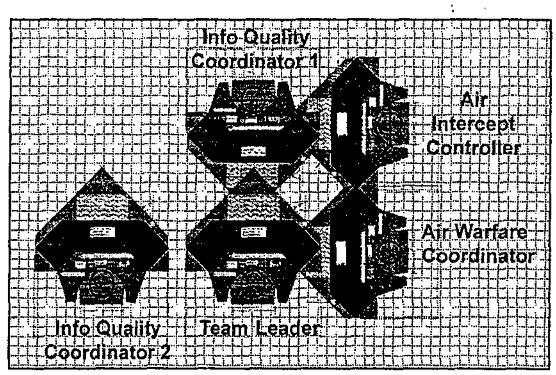


Figure 20.8 Integrated Command Environment Lab. MMWS team performance testing (left) and team positions (right).

- Verify positive communications and communication equipment check for departing strike force aircraft.

Results for time and accuracy of reporting new tracks to the battlegroup are shown in Figures 20.9 and 20.10. There was a large decrease in performance variability from the AEGIS crews to MMWS versions BC1 and EC2. The results are shown for the first and second half of the scenario test period, with the first half being the lower workload period. Note that performance variance decreases for the Basic and Enhanced MMWS design in both the low and high workload periods. The low, medium, and high ranked tracks within 25 critical scenario events are shown, with indication that MMWS teams were better able to balance their workload among the types of scenario events.

The "overall" score shows a summary of all scenario periods with a similar decrease in variance. The high variance of results with legacy system teams requires a large number of subjects (greater than 20 teams calculated) to allow for inferential statistics. The low variance of performance with MMWS indicates that an increased homogeneity of response may be possibly a result of the design features guiding user information processing through the task cycle.

Figure 20.10 indicates that fewer MMWS users missed performing the report tasks, with only one report missed by the two MMWS EC teams tested. There were fewer missed tasks in the first and second scenario periods, with reduced performance variance. The legacy system relies on poorly coded graphic displays with a burden on human visual search tasking to locate and define task opportunities.

The MMWS provides enhanced visual cues for task initiation yielding fewer missed task opportunities. Table 20.11 shows SA results for a few of the critical scenario events. Track number 132 was a critical event where evidence was built over several minutes that the track might have hostile intentions toward the friendly forces. *The track eventually*

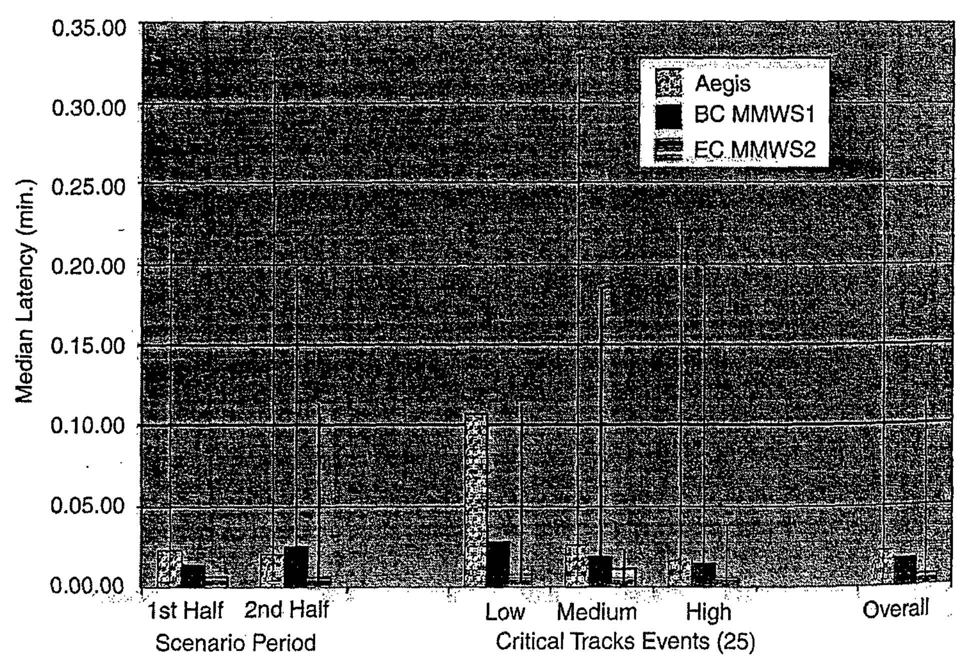


Figure 20.9 Median latency.

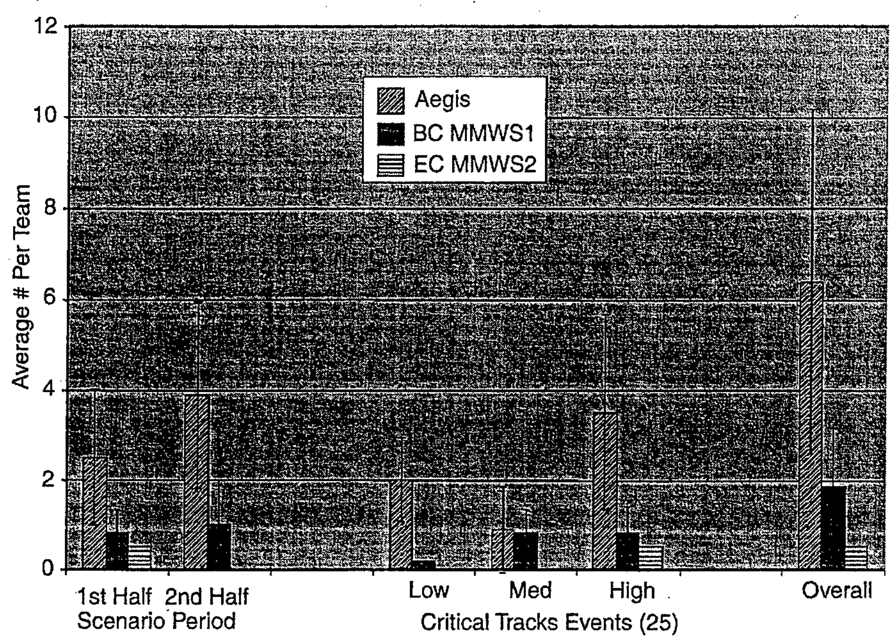


Figure 20.10 Averaged number of missed new track reports.

attacks friendly forces. Note that all the MMWS teams followed the information changes about the track represented by kinematic cues (course, speed, altitude, position) and exhibited markedly improved SA as evidenced by their preparations in issuing queries or warnings leading up to the time of attack. In comparison, most of the AEGIS teams using the legacy equipment missed key kinematic events, and few teams issued queries or warnings and responded with last second engagement responses after the attack. Thus, the engagement outcome may be successful with legacy systems, but the risk is higher due to shortened reaction times with lower SA. Figures 20.9 and 20.10 represent a small subset of data collected, and further testing is required to replicate results with larger sample sizes. The team testing results correlated very well with the speed and accuracy results obtained with the same tasks and scenario with individual operators during usability testing.

Workload was measured by ratings of subject experts who observed the crew members and by crew members themselves during scenario breaks. Figure 20.11 presents the results of the expert raters. Although the raters were not condition blind, considerable time passed between the legacy system data collection and MMWS collections (one year). *Results*

TABLE 20.11 Summary of AEGIS and MMWS Responses to Critical Track Number TN 132

Teams	Kinematics Detected	Query/Warnings Issued	Engage Antiship Missile (ASM) after attacked
AEGIS teams	1 of 8	2 of 8	7 of 8
MMWS BC1	6 of 6	6 of 6	6 of 6
MMWS EC2	2 of 2	2 of 2	2 of 2

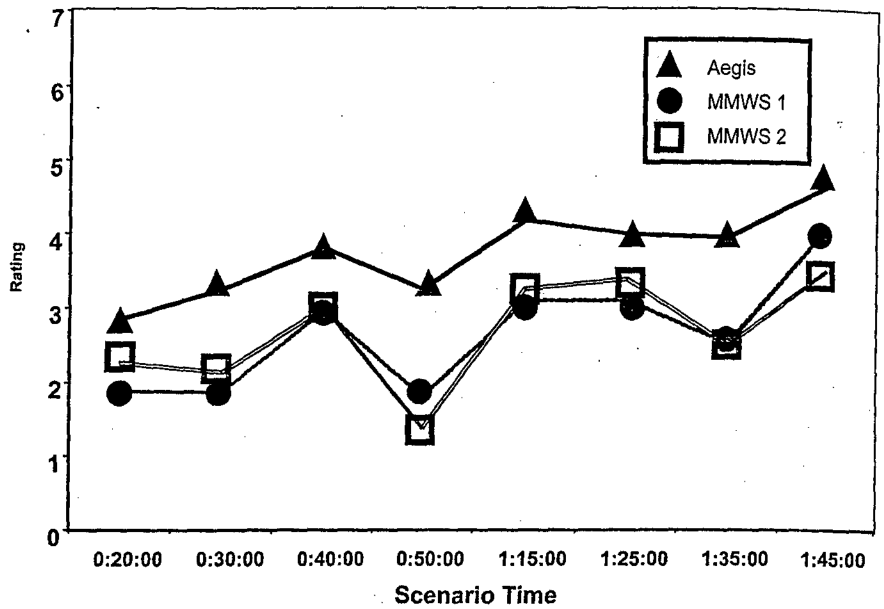


Figure 20.11 Subject expert ratings of workload (1 = low, 7 = high) over entire scenario period for MMWS and ship board systems.

indicate that despite the smaller teams used with MMWS, the crews were not overloaded in comparison to the larger crews using the legacy system.

20.8.2 Training Results

Training requirements for ship crews included knowledge and skills applied across several task domains: (1) warfighting and mission, (2) individual responsibility and team role, (3) system Command and Control (C^2), (4) verbal communications, and (5) work strategy, planning, and prioritization. Subjects used in team testing were experts in the mission domain and required no training in mission tasks. They were skilled in communications methods and vocabulary used today. Training was required in system C^2. The watchstation training required a minimum of 1 to 2 hours for simple usability studies and tasks. Approximately 6 to 8 hours of training were required for full team testing. Teams intact from ships had previous experience of working together as a unit. Teams composed of training personnel or instructors were familiar with individual tasks but not as working together as a unit.

Both teams performed well with no detected difference in results. Results indicated that despite being challenged by new symbols, graphics, operating procedures, and display formats, that the crews using MMWS performed as well or better than the larger intact shipboard teams. The TCD plays an important role in facilitating training by providing a design focus on simple procedures across many tasks. Most MMWS tasks could be performed using identical procedural steps, allowing for simple procedural knowledge training that could be extrapolated across many work activities. Personnel commented following training that the watchstation and associated displays and tasks were easy to learn and could condense the longer training courses of today's workstations into a shorter time period.

20.9 SUMMARY AND CONCLUSIONS

Evidence from performance studies supports the hypothesis that the MMWS design may improve mission performance and reduce mission risk. Training complexity and burden are also significantly reduced. While there appears to be a performance gain from the Basic- to Enhanced-capability MMWS, there is still too little data to make firm conclusions. The TM, decision aids, and dynamic RPM in the Enhanced MMWS version appear to reduce performance variance and possibly improve decision reaction time and reduce missed tasks. The task-centered approach focused the design effort on critical tasks needed to complete a complex mission scenario. This approach directed the design cost toward the necessary display and control elements to get the "core" work done.

The cost benefit of these results, as well as the potential for crew size optimization due to lower workload and improved task execution, project a significant role for the application of task-centered human engineering in future work environments. These results apply across various task domains in other mission areas and in ship propulsion and control systems.

A central design theme in MMWS was the evolution of the human role in many C^2 tasks from being a manual preparation of task products to the supervisor and reviewer of draft task products. The human is better able to allocate resources to planning and strategy tasks that are difficult for the machine, and the machine off-loads the rule-based tasks from the human, with a reliable and repeatable result. The challenge then exists to make these machine assistants increasingly flexible and pliable under a variety of task conditions and demands, while keeping the human informed to monitor, supervise, and approve task activities.

20.9.1 HSI Principles

Clearly, the focus on HCD in the MMWS design illustrates an example of principle 2, described in Chapter 1. But what of the other principles? The context of where MMWS fits in the design process also illustrates the relevance of several other HSI principles. Certain principles apply more to the early concept design phase during research and development (R&D) whereas others are more appropriate during later stages of design.

Leadership (principle 1) is critical to the viability of any project and program from concept through fielding. For innovative R&D concepts, leadership is necessary to see a state of design beyond what exists today. The ability to sell this "vision" to leadership in the procurement and funding allocation roles is critical. In the case of MMWS, navy leadership puts forth a vision of reduced crews on ships, driven by cost and budgeting realities, as well as recruiting and personnel projections. This in turn led to the requirement for improvement in human engineering and crew workload. The conceptual design phase of MMWS required leadership with a sense of vision that HSI methods and processes could be improved relative to the state-of-art for today. Project leaders had to be convinced that this goal was worthwhile as part of a global crew reduction HSI strategy.

The MMWS project had an interesting and unplanned benefit for the *source selection process* (principle 3) and *documentation integration* (principle 5). Military requirements policymakers are increasing both the content and strength of verbiage applied to HSI in procurement documents for future systems. The recently released Land-Attack Training Guidance document (Chief of Naval Operations, 2001) is a good example. Notably, it

requires program executive offices and program managers to plan and budget for HSI support activities during design and procurement. The document also states that "System operation and watchstanding requirements may be reduced through . . . Enhanced system ergonomic and Human Centered Designs that improve the performance and efficiency of watchstanders, especially in the areas of information management and operator interfaces . . . [and] Use of multi-modal watch stations that permit task sharing and optimize workload within the watch team." The document also specifies working–level integrated product teams (WIPTs) that specifically include HSI and HCD as prime considerations. From the government point of view, the systems acquisition documentation should include greater emphasis on HCD. From the contractors point of view, contract awards should be given to those with best HCD technical approach.

HSI technologies (principle 7) are recognized to be fast moving targets with commercial hardware advancements occurring in rapid succession. An important goal of HSI, therefore, must be to provide guidance with regard to HCI architecture. Systems that place HCI functions in a software layer as either independent or plug-in components allow for further upgrades and adaptation as technology quickly evolves. The concept of TCD fits the plug-and-play architecture very well as task components are upgraded and added through an evolutionary approach. The software design process also benefits from the testing and debugging afforded by a modular approach to architecture.

Testing and performance evaluation (principle 8) is a critical part of the design process. The process of evolutionary design and usability testing differs from the more conventional hierarchical linear design method that includes user testing at the end of the design process. With iterative design, risk is mitigated by usability testing starting with early conceptual walkthroughs on paper or by creating low-fidelity simulations in general-purpose presentation tools such as Microsoft PowerPoint before any code is written and while requirements are in formation. While the team performance tests were useful in the MMWS design process, the numerous usability tests through 2 years of multiple software versions held the most value for risk reduction. Design ideas were very much changed or discarded that had looked good on paper but failed due to a combination of dynamic task demands and lower than expected utility with operators. Programs that delay user testing and hands-on interaction until later stages of design incur unnecessary risk with respect to user performance and acceptance.

The use of *highly qualified human factors practitioners* (principle 9) contributed strongly to the MMWS design process. The design requirements were stated and held as design goals by a qualified Ph.D. human factors professional. There were occasions where the project team considered a design path directed toward a solution that was expedient for software risk or acceptance of a commercial product solution that did not appear to support human performance in a desirable manner. A qualified professional can screen the design options and select options based on HCD goals and performance improvement. Many HSI aspects of the design process are invisible to the nonqualified engineer who might be placed in charge of HSI by program management. One of the most difficult issues in using checklists or guidance information is the comparison of the task conditions represented in the guidelines to the task conditions in the current problem. The designer must recognize whether task differences are meaningful and what aspects of human performance are affected by these differences. Another important facet of professional support is the evolving literature and technologies surrounding the HCI. This fast-paced evolution requires dedicated professionals to keep abreast of changes relevant to any engineering project.

20.9.2 Navy HSI Capability Maturity

In general, it can be said that within the navy, the underlying government procurement organization structure is trying to enhance recognition of HSI considerations during design. In most program execution offices, however, the HSI responsibilities still are buried at a level far down in the organization hierarchy and typically as a collateral duty. The procurement officer may be in the hardware display or information systems component of the project. The prevalent conception among the engineering community is that the HSI issues revolve around display formats or use of color formatting at a superficial design level. Human factors professionals are not consulted during the system requirements definition phases or other early design processes.

Moreover, even though there is increased recognition that usability is a system design requirement having great importance, there is little R&D or development funding to follow through in improving HSI nor are there penalties for HSI ignorance. Design problems are often passed along as issues that the training community must address when the system is fielded. The Department of Defense (DoD) engineering community still attacks the myriad of problems in complex information and C^2 systems from a network and hardware architecture perspective, with HSI narrowly seen as a problem of maintaining consistency in the graphics user interface (GUI). Performance goals or requirements are not quantified, leaving no specific human performance requirements with which to test design success or failure. Thus, currently, the many components of HSI do not drive broader design solutions, and the main tenants of task coverage and dynamic task life-cycle support discussed in this chapter are not widely known or considered.

However, design success stories such as MMWS should increase the education and awareness level of management, while increasing the awareness of the user community that improved HSI is feasible. If user-centered design processes and successful results increase the number of visible system successes, particularly with respect to system life-cycle costs, the prospects for improved HSI during the design process will increase.

NOTE

1. MMWS was conceived by the Space & Naval Warfare Systems Center, San Diego and supported under the DD21/ONR Manning Affordability Program executed through the Office of Navy Research, Arlington, Va.

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